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ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TESTS J4-1801-34 THROUGH 36)

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ARO, Inc.

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LARGE ROCKET FACILITY

ARNOLD ENGINEERING DEVELOPMENT CENTER

AIR FORCE SYSTEMS COMMAND

ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

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FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC) (I-E-J), under System 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract F40600-69-C-0001. Program direction was provided by NASA/MSFC; engineering liaison was provided by North American Rockwell Corporation, Rocketdyne Division, manufacturer of the J-2 rocket engine, and McDonnell Douglas Corporation, Douglas Aircraft Company, Missile and Space System Division, manufacturer of the S-IVB stage. The testing reported herein was conducted on March 27 and April 2 and 10, 1968, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1801. The manuscript was submitted for publication on July 17, 1968.

This technical report has been reviewed and is approved.

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ABSTRACT

Twelve firings of the Rocketdyne J-2 rocket engine (S/N 2047) were conducted in Test Cell J-4 of the Large Rocket Facility on March 27 and April 2 and 10, 1968. These firings were accomplished during test periods J4-1801-34, J4-1801-35, and J4-1801-36 at pressure altitudes of approximately 100,000 ft at engine start to investigate S-IVB (1) first burn firings, (2) 6-hr orbital coast restart simulation firings, (3) 80-min orbital coast restart simulation firings, and (4) a partial transition firing to evaluate thrust chamber conditioning temperature effects on engine start transients. Engine operation was satisfactorily accomplished for all firings. One abort resulted when a leak developed in the diaphragm of the engine pneumatic regulator. The accumulated firing duration for the three test periods was 205 sec. The total firing duration of this engine at AEDC through test period J4-1801-36 is 1141 sec resulting from 91 engine firings.

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APPENDIXES

NOMENCLATURE

A	Area, in.^{2}
ASI	Augmented spark igniter
ES	Engine start, designated as the time that helium control and ignition phase solenoids are energized
GG	Gas generator
MOV	Main oxidizer valve
STDV	Start tank discharge valve
t_0	Defined as the time at which the opening signal is applied to the start tank discharge valve solenoid
VSC	Vibration safety counts, defined as engine vibration in excess of 150 g rms in a 960- to 6000-Hz frequency

SUBSCRIPTS

f	Force
m	Mass
t	Throat

SECTION I
INTRODUCTION

Testing of the Rocketdyne J-2 rocket engine using an S-IVB battleship stage has been in progress since July 1966 at AEDC in support of the J-2 engine application on the Saturn IB and Saturn V launch vehicles for the NASA Apollo Program. The 12 firings reported herein were conducted during test periods J4-1801-34, J4-1801-35, and J4-1801-36 on March 27 and April 2 and 10, 1968, respectively, in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF) to investigate S-IVB first burn, 6-hr orbital coast restart, and 80-min orbital coast restart simulation firings. These firings were accomplished at pressure altitudes of approximately 100,000 ft (geometric pressure altitude, Z, Ref. 1) at engine start.

Data collected to accomplish the test objectives are presented herein. The results of the previous test period are presented in Ref. 2.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2 rocket engine (S/N 2047) (Fig. 3) designed and developed by Rocketdyne Division of North American Rockwell Corporation. The engine uses liquid oxygen and liquid hydrogen as propellants and has a thrust rating of 230,000 lb_f at an oxidizer-to-fuel mixture ratio of 5.5. An S-IVB battleship stage, with flight-type S-IVB stage low pressure propellant supply ducts, was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of major engine components and engine orifices for this test period are presented in Tables I and II, respectively (Appendix II). All engine modifications and component replacements performed since the previous test period are presented in Tables III and IV, respectively.

2.1.1 J-2 Rocket Engine

The J-2 rocket engine (Figs. 3 and 5, Ref. 3) features the following major components:

1. Thrust Chamber - The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in.-diam combustion chamber (8.0 in.

long from the injector mounting to the throat inlet) with a characteristic length (L*) of 24.6 in., a 170.4-$in.^2$ throat area, and a divergent nozzle with an expansion ratio of 27.1. Thrust chamber length (from the injector flange to the nozzle exit) is 107 in. Cooling is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector.

2. Thrust Chamber Injector - The injector is a concentric-orificed (concentric fuel orifices around the oxidizer post orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 25.0 and 16.0 $in.^2$, respectively. The porous material, forming the injector face, allows approximately 3.5 percent of total fuel flow to transpiration cool the face of the injector.

3. Augmented Spark Igniter - The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber. The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs.

4. Fuel Turbopump - The turbopump is composed of a two-stage turbine-stator assembly, an inducer, and a seven-stage axial-flow pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 38,215 ft (1248 psia) of liquid hydrogen at a flow rate of 8585 gpm for a rotor speed of 27,265 rpm.

5. Oxidizer Turbopump - The turbopump is composed of a two-stage turbine-stator assembly and a single-stage centrifugal pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 2170 ft (1107 psia) of liquid oxygen at a flow rate of 2965 gpm for a rotor speed of 8688 rpm.

6. Gas Generator - The gas generator consists of a combustion chamber containing two spark plugs, a pneumatically operated control valve containing oxidizer and fuel poppets, and an injector assembly. The oxidizer and fuel poppets provide a fuel lead to the gas generator combustion chamber. The high energy gases produced by the gas generator are directed to the fuel turbine and then to the oxidizer turbine (through the turbine crossover duct) before being exhausted into the thrust chamber at an area ratio (A/A_t) of approximately 11.

7. Propellant Utilization Valve - The motor-driven propellant utilization valve is mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.

8. Propellant Bleed Valves - The pneumatically operated fuel and oxidizer bleed valves provide pressure relief for the boiloff of propellants trapped between the battleship stage prevalves and main propellant valves at engine shutdown.

9. Integral Hydrogen Start Tank and Helium Tank - The integral tanks consist of a 7258-$in.^3$ sphere for hydrogen with a 1000-$in.^3$ sphere for helium located within it. Pressurized gaseous hydrogen in the start tank provides the initial energy source for spinning the propellant turbopumps during engine start. The helium tank provides a helium pressure supply to the engine pneumatic control system.

10. Oxidizer Turbine Bypass Valve - The pneumatically actuated oxidizer turbine bypass valve provides control of the fuel turbine exhaust gases directed to the oxidizer turbine in order to control the oxidizer-to-fuel turbine spinup relationship. The fuel turbine exhaust gases which bypass the oxidizer turbine are discharged into the thrust chamber.

11. Main Oxidizer Valve - The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer high pressure duct between the turbopump and the main injector. The first-stage actuator positions the main oxidizer valve at the 14-deg position to obtain initial thrust chamber ignition; the second-stage actuator ramps the main oxidizer valve full open to accelerate the engine to main-stage operation.

12. Main Fuel Valve - The main fuel valve is a pneumatically actuated butterfly-type valve located in the fuel high pressure duct between the turbopump and the fuel manifold.

13. Pneumatic Control Package - The pneumatic control package controls all pneumatically operated engine valves and purges.

14. Electrical Control Assembly - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation.

15. Primary and Auxiliary Flight Instrumentation Packages - The instrumentation packages contain sensors required to monitor critical engine parameters. The packages provide environmental control for the sensors.

2.1.2 S-IVB Battleship Stage

The S-IVB battleship stage is approximately 22 ft in diameter and 49 ft long and has a maximum propellant capacity of 46,000 lb of liquid hydrogen and 199,000 lb of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant prevalves, in the low pressure ducts (external to the tanks) interfacing the stage and the engine, retain propellant in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Propellant recirculation pumps in both fuel and oxidizer tanks are utilized to circulate propellants through the low pressure ducts and turbopumps before engine start to stabilize hardware temperatures near normal operating levels and to prevent propellant temperature stratification. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen for fuel tank pressurization during S-IVB flight was routed to the facility vent system.

2.2 TEST CELL

Test Cell J-4, Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion systems at pressure altitudes of 100,000 ft. The basic cell construction provides a 1.5-million-lbf-thrust capacity. The cell consists of four major components (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), and liquid oxygen and gaseous helium storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 4.

The battleship stage and the J-2 engine were oriented vertically downward on the centerline of the diffuser-steam ejector assembly.

This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown. The test cell was also equipped with (1) a gaseous nitrogen purge system for continuously inerting the normal air in-leakage of the cell; (2) a gaseous nitrogen repressurization system for raising test cell pressure, after engine cutoff, to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; and (3) a spray chamber liquid nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

An engine component conditioning system was provided for temperature conditioning engine components. The conditioning system utilized a liquid hydrogen-helium heat exchanger to provide cold helium gas for component conditioning. Engine components requiring temperature conditioning were the thrust chamber, crossover duct, and main oxidizer valve second-stage actuator. Helium was routed internally through the crossover duct and tubular-walled thrust chamber and externally over the main oxidizer valve second-stage actuator.

2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation was comprised of (1) flight instrumentation for the measurement of critical engine parameters and (2) facility instrumentation which was provided to verify the flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and periodically recalibrated at AEDC. Appendix III contains a list of all measured test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage-type pressure transducers. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and fuel turbopump shaft speeds were sensed by magnetic pickup. Fuel and oxidizer flow rates to the engine were measured by turbine-type flowmeters which are an integral part of the engine. The propellant

recirculation flow rates were also monitored with turbine-type flowmeters. Vibrations were measured by accelerometers mounted on the oxidizer injector dome and on the turbopumps. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by (1) precision electrical shunt resistance substitution for the pressure transducers and resistance temperature transducer units; (2) voltage substitution for the thermocouples; (3) frequency substitution for shaft speeds and flowmeters; and (4) frequency-voltage substitution for accelerometers.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system (MicroSADIC®) scanning each parameter at 40 samples per second and recording on magnetic tape; (2) single-input, continuous-recording FM systems recording on magnetic tape; (3) photographically recording galvanometer oscillographs; (4) direct-inking, null-balance potentiometer-type X-Y plotters and strip charts; and (5) optical data recorders. Applicable systems were calibrated before each test (atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing, as well as for replay capability for immediate examination of unexpected events.

2.4 CONTROLS

Control of the J-2 engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A schematic of the engine start control logic is presented in Fig. 6. The sequence of engine events for a normal start and shutdown is presented in Figs. 7a and b. Two control logics for sequencing the stage prevalves and recirculation systems with engine start for simulating engine flight start sequences are presented in Figs. 7c and d.

SECTION III
PROCEDURE

Preoperational procedures were begun several hours before the test period. All consumable storage systems were replenished, and

engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer dome, gas generator oxidizer injector, and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust-ducting atmosphere was inerted. At this same time, the cell nitrogen purge was initiated for the duration of the test period, except for the engine firing. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Temperature conditioning of the various engine components was accomplished as required, using the facility-supplied engine component conditioning system. Engine components which required temperature conditioning were the thrust chamber, the crossover duct, and main oxidizer valve second-stage actuator. Table V presents the engine purges and thermal conditioning operations during the terminal countdown and immediately following the engine firing.

SECTION IV
RESULTS AND DISCUSSION

4.1 TEST SUMMARY

Twelve firings of the J-2 rocket engine were conducted during tests J4-1801-34, J4-1801-35, and J4-1801-36 on March 27 and April 2 and 10, 1968, respectively, for a total firing duration of 204.7 sec. These firings were in support of the S-IVB/S-V J-2 engine developmental program. Engine components were thermally conditioned to temperatures predicted for S-IVB/S-V first burns, 80-min one-orbit coast restarts, and 6-hr orbital coast restarts. A propellant utilization valve excursion

from null to the full-closed position (nominal oxidizer-to-fuel mixture ratio change from 5.0 to 5.5) at t_0 + 10 sec was accomplished on first burn simulation firings and from the open position to full-closed position (nominal oxidizer-to-fuel mixture ratio change from 4.5 to 5.5) on 6-hr orbital coast restarts. All 80-min one-orbit coast restarts were accomplished with the propellant utilization valve in the full-open position. Test requirements and specific test results are summarized in Table VI. Start and shutdown times of selected engine valves are presented in Table VII. The pump inlets, start tank, and helium tank pressure and temperature conditions at engine start are shown in Fig. 8.

Test period J4-1801-34 included two S-IVB restart couples (each couple consisting of a first burn and an 80-min orbital coast). A fifth test (firing 34C) was terminated prematurely by an erroneous engine vibration safety cutoff (VSC) that resulted from a broken electrical connector to an engine accelerometer. Only two of five scheduled firings were conducted during test period J4-1801-35. The engine pneumatic regulator failed on the J4-1801-35C attempt, and remaining scheduled firings were cancelled. The pneumatic regulator was replaced before test 36; an inspection of the faulty regulator indicated a leaky diaphragm. All firings of J4-1801-36, consisting of two S-IVB restart couples (the first couple consisted of a 6-hr orbital coast restart followed by an 80-min orbital coast restart; the second couple consisted of a first burn and an 80-min orbital coast restart) and one partial transition S-IVB first burn, were successfully completed.

Specific test objectives and a brief summary of results obtained for each firing are presented as follows:

Firing	Objectives	Results
34A	Conduct a 32.5-sec S-IVB first burn simulation firing to evaluate effects of (1) maximum start energy, (2) minimum fuel pump inlet pressure, and (3) warmest expected thrust chamber on the augmented spark igniter and gas generator temperature transients.	This firing was satisfactorily completed with no apparent augmented spark igniter chamber erosion. The gas generator outlet temperature initial peak was 1645°F with a 1700°F second peak.

Firing	Objectives	Results
34B	Conduct a 7.5-sec S-IVB 80-min restart simulation firing to evaluate engine transients with start tank conditions expected with a narrow band start tank relief valve.	The firing was satisfactorily conducted at the specified start conditions. Engine transient operation appeared normal.
34C	Conduct a 32.5-sec S-IVB first burn with requirements selected for comparison with firing 34A to evaluate the effect of a 175°F colder thrust chamber temperature on engine start transient.	An erroneous indication of excessive engine vibration caused a premature termination at t_0 + 2.7 sec. The excessive vibration indication was caused by a broken connector on an accelerometer. Transient data indicated a 370 deg higher gas generator outlet temperature and 30 msec longer engine vibrations with the colder thrust chamber.
34D	Conduct a 32.5-sec S-IVB first burn simulation firing with requirements selected for comparison with firing 34A to evaluate the effect of 150 psi lower and 60°F warmer start tank conditions at engine start.	The firing was satisfactorily conducted at the reduced start tank energy. The gas generator outlet temperature, initial and second peaks, was 85 and 210°F lower on firing 34D. No adverse engine transient operation was observed.
34E	Conduct a 7.5-sec S-IVB 80-min restart firing with requirements selected for comparison with firing 34B to evaluate the effect of a 50°F colder start tank temperature.	The firing was satisfactorily conducted at the reduced start tank temperature. The initial gas generator outlet temperature was 225°F higher on firing 34E; the second peak was 40°F lower on firing 34E. The engine exhibited a faster buildup to steady state on firing 34E.
35A	Conduct a 32.5-sec S-IVB first burn simulation to evaluate engine start	The firing was successfully conducted. Engine vibrations were recorded for 24 msec at

Firing	Objectives	Results
35A (Con't)	transient and thrust chamber instability at start tank conditions of 1400 psia and -140°F and minimum thrust chamber temperature.	chamber ignition, a relatively short duration. The gas generator outlet temperature initial and second temperature peaks were 1915 and 1435°F, respectively.
35B	Conduct a 7.5-sec S-IVB 80-min restart simulation firing to evaluate engine start transients with minimum start tank energy expected with a selected narrow band start tank relief valve.	The 80-min restart simulation firing was successfully conducted. Engine transient data indicated normal and satisfactory operation.
35C	Conduct a 32.5-sec S-IVB first burn with requirements selected for comparison with firing 35A to evaluate the effect of a 60°F colder start tank and increased fuel pump inlet pressure on engine start transient and thrust chamber instability.	This firing attempt was aborted when the engine helium regulator failed.
36A	Conduct a 32.5-sec S-IVB 6-hr orbital coast restart simulation to evaluate starting characteristics at low energy conditions.	The firing was successfully conducted. The initial gas generator outlet temperature was 880°F, the lowest peak recorded for J-2 engine operation at AEDC to date. In addition, engine chamber pressure buildup to 550 psia occurred at t_0 + 2.8 sec, the longest to date.
36B	Conduct a 7.5-sec S-IVB 80-min restart simulation firing to evaluate engine transients with narrow band start tank relief valve.	The firing was successfully conducted at the specified conditions except that turbine hardware temperature was 2°F below specified limits at engine start. Engine transient operation appeared normal and satisfactory.

Firing	Objectives	Results
36C	Conduct a 7.5-sec S-IVB first burn simulation to evaluate augmented spark igniter and gas generator temperature transients using maximum start tank energy and fuel pump inlet pressure.	All objectives of this firing were accomplished. A relatively high gas generator outlet temperature peak of 2140°F was recorded; no augmented spark igniter chamber erosion was noted after the test period.
36D	Conduct a 7.5-sec S-IVB 80-min restart simulation firing with requirements selected for comparison with firing 36B to evaluate effect of 100 psi higher and 5°F colder start tank conditions.	Objectives of this firing were accomplished. The gas generator outlet temperature, initial peak, was 2160°F, 190°F higher than recorded on firing 36B. Engine buildup time to steady state was less for firing 36D.
36E	Conduct a 1.1-sec partial transition firing to evaluate thrust chamber temperature effect on engine start transient (particularly low level stall margin) and for relief of launch constraint.	No fuel pump stall tendencies were noted with a 0°F thrust chamber temperature and 3-sec fuel lead. All objectives were accomplished.

The presentation of the test results in the following sections will consist of a discussion of selected engine firings with pertinent comparisons and analysis. Start and shutdown transients for each firing are presented in Figs. 9 through 56. All data presented were recorded on the digital data acquisition system, except as noted.

A momentary delay during the initial gas generator outlet temperature rise was observed on three one-orbit restart firings (34B, 34E, and 36B) and two S-IVB first burns (firings 34A and 35A). An investigation of engine operation failed to indicate a logical reason for the irregular temperature rise. One of the two gas generator outlet temperature sensors was found eroded after test 36 and was replaced. A checkout of the probe at ambient conditions indicated normal resistance. It appears that at cryogenic conditions, abnormal resistance developed in the probe producing an erroneous temperature indication. However, for the tests reported herein, the gas generator outlet temperatures followed an expected trend, indicating that if a bias exists, it is repeatable.

4.2 START TRANSIENT INVESTIGATION

The following sections are devoted to an investigation of the effects that various starting conditions have on engine transient operation. Specific conditions that affect the engine transient and are investigated herein include (1) thrust chamber conditioning temperature, (2) start tank temperature, (3) start tank pressure, and (4) fuel pump NPSH. For each comparison, the start conditions are similar except for the variable involved, or as noted; where possible, the effect that the variable has on first burn simulation firings is first shown, followed by a discussion of the effect on 80-min restart. A discussion of engine start transient for a low energy S-IVB 6-hr orbital coast restart and a partial transition firing conducted with a 0°F thrust chamber temperature is also included.

4.2.1 Thrust Chamber Temperature Effect on Start Transient

4.2.1.1 S-IVB First Burn

Firings 34C, 34A, and 36E were conducted with thrust chamber throat temperatures of -239, -85, and -8°F, respectively, at engine start and are compared in Fig. 57. The average thrust chamber conditioning temperatures at both engine start and start tank discharge valve solenoid energized (t_0), gas generator outlet temperature (initial peak), thrust chamber ignition time, and engine vibration duration are summarized as follows:

Firing	Average Thrust Chamber Temperature, Engine Start and t_0, °F	Gas Generator Outlet Temperature, Initial Peak, °F	Thrust Chamber Ignition Time, sec	Engine Vibration Duration, msec
34C	-289/-358	2015	$t_0 + 0.982$	47
34A	-111/-184	1645	$t_0 + 0.957$	17
36E	-14/-91	1585	$t_0 + 0.975$	---

The warmer thrust chamber temperature provided higher fuel system resistance, increasing the initial fuel pump discharge pressure and gas generator power. The three firings exhibited an average of 1.5°F increase in the gas generator outlet temperature initial peak for each 1°F

decrease in the thrust chamber body temperature. No significant second peaks were observed. Engine thrust chamber pressure buildup rate was faster with the warmer thrust chamber because of increased gas generator power. No engine vibrations (VSC) were experienced with the warmest thrust chamber on firing 36E.

The fuel pump head-flow start transient performance for the three firings is compared with the stall inception line in Fig. 58. The stall margin increased as the thrust chamber temperature was decreased. The stall margin, however, was conservative in each case.

4.2.1.2 S-IVB 80-min Orbital Coast Restart Simulation Firing

Average thrust chamber body temperature at engine start for firings 36D and 34E was -210 and +56°F; when start tank discharge valve solenoid energized, after an 8-sec fuel lead, average thrust chamber body temperature was -362 and -200°F, respectively. As shown in Fig. 59, the gas generator outlet temperature, initial peak, was lowered by the warmer thrust chamber. An initial peak of 2160°F was experienced on firing 36D with the colder thrust chamber; no second peak was observed. With a 162°F warmer thrust chamber on firing 34E, an initial peak of 1905°F was observed, with a second peak of 1880°F. The turbine component temperature averaged 22°F warmer (average of TFTD-2, -3, and -8) on firing 36D which would contribute some to the higher gas generator outlet temperature initial peak on firing 36D. These two S-IVB restart firings exhibited a 1.6°F increase in the gas generator outlet temperature initial peak for each 1°F decrease in thrust chamber body temperature.

The main oxidizer valve second-stage initial opening movement occurred 150 msec sooner on firing 36D then on firing 34E. The main oxidizer valve was reorificed before test 36 to reduce the second-stage sequence ramp time by about 30 msec. In addition, with the warmer thrust chamber on firing 34E, a higher fuel weight flow is supplied to the gas generator. This provided a higher gas generator power and increased the oxidizer pump discharge pressure. The increased discharge pressure created a hydraulic torque that reacted against the main oxidizer valve pneumatic opening pressure and delayed the initial second-stage opening time. The gas generator outlet temperature, second peak, observed on firing 34E resulted from the delayed second-stage movement. Thrust chamber ignition occurred at t_0 + 0.953 and 0.957 sec, respectively, for firings 34E and 36D. This initiated the mechanism for reducing the gas generator initial temperature peak at about the same time.

Fuel pump start transient head-flow performance for the two thrust chamber temperature conditions is compared with the stall inception line in Fig. 60. As can be observed, the stall margin was more conservative with the colder thrust chamber until main chamber ignition. After thrust chamber ignition, until about t_0 + 1.3 sec, a more conservative stall margin was observed with the warmer thrust chamber.

The duration of engine vibrations (VSC) was much longer with the colder thrust chamber. Approximately 110 msec was observed on firing 36D with the cold chamber; on firing 34E, a duration of 5 msec was recorded with a warmer chamber.

4.2.2 Start Tank Gas Temperature Effect on Start Transient

The effect of start tank gas temperature depends to a large extent on the turbine crossover duct temperature. The greater the temperature differential between the start tank gas and crossover duct, the higher the energy imparted to the start tank gas during discharge. The ratio of oxidizer/fuel turbopump energy supply is consequently raised, resulting in an increased oxidizer-to-fuel flow to the gas generator and thrust chamber.

4.2.2.1 S-IVB First Burn

The effects on engine operation of -201 and -136°F start tank gas temperature (firings 34C and 35A, respectively) are shown in Fig. 61. The crossover duct temperature was ambient for both firings but was 40°F warmer on firing 34C (as indicated by TFTD-3). Although a comparison of the initial gas generator outlet temperature peak indicates about 100°F higher for firing 34C with the colder start tank gas temperature, two other factors exist that contribute some to this difference. First, the thrust chamber body average temperature at t_0 was 18°F colder on firing 34C, which would tend to increase the initial peak approximately 30°F (see Section 4.2.1). Second, the crossover duct temperature was 40°F warmer on firing 34C, which would also tend to increase the initial peak. Since these two differences exist, a direct comparison of start transients would not be valid. However, it can be observed that the start tank temperatures used for these two firings had little effect on the gas generator outlet temperature, initial peak, with ambient temperature turbine hardware.

Thrust chamber ignition occurred 22 msec sooner on firing 34C with the colder start tank gas temperature (chamber ignition times were 0.982 and 1.004 on firings 34C and 35A, respectively). Engine vibrations (VSC) recorded for the two firings were 47 and 24 msec on firings 34C and 35A, respectively.

Fuel pump head-flow start transient performance for these two firings is compared with the stall inception line in Fig. 62. The high level stall margin was more conservative with the colder start tank on firing 34C.

4.2.2.2 S-IVB 80-min Orbital Coast Restart Simulation Firing

The effects on engine transient operation of -268 and -216°F start tank temperature (firings 34E and 34B, respectively) with warm crossover duct temperatures are shown in Fig. 63. The gas generator initial temperature peak on firing 34E was 1905°F with the colder start tank gas; the initial peak on firing 34B was 1680°F, 225°F lower with the warmer start tank gases. The crossover duct temperature (as indicated by TFTD-3) was 5°F warmer on firing 34B but would contribute only a very small percentage to the difference observed between the two initial temperature peaks. These firings indicate a 4.3°F increase in the gas generator outlet temperature, initial peak, for a 1°F decrease in start tank temperature. Main chamber ignition occurred at t_0 + 0.953 and 0.974 sec for firings 34E and 34B, respectively, 21 msec sooner with the colder start tank gases. The higher gas generator outlet temperature and faster thrust chamber ignition time with colder start tank gas conditions result from a higher initial total energy in the start tank and increased energy transfer to the gases from warm turbine hardware during discharge. Both firings exhibited a second peak gas generator outlet temperature, with values of 1920 and 1880°F recorded on firings 34B and 34E, respectively.

Start transient fuel pump head-flow performance for these two firings is compared with the stall inception line in Fig. 64. As can be observed, there is little difference in the stall margin, and the margin is extremely conservative in each case.

The duration of engine vibrations (VSC) was relatively short for each firing. Approximately 7 msec was recorded on firing 34B, and 5 msec on firing 34E.

4.2.3 Start Tank Pressure Effect on Start Transients

4.2.3.1 S-IVB First Burn

This series of tests did not include two first burn firings with start tank pressure as the only variable. However, a start tank pressure gain factor for an S-IVB first burn was investigated and reported on in a previous report (Ref. 5). In this report, it was noted that a 147-psia increase in start tank pressure resulted in a 240°F increase in the gas generator outlet temperature, initial peak.

4.2.3.2 S-IVB 80-min One-Orbit Restart

Firings 35B and 34B were conducted with start tank pressures of 1174 and 1294 psia, respectively, to investigate the pressure effects on the engine starting transient. Start tank temperatures were -209 and -216°F, respectively, on firings 35B and 34B. As shown in Fig. 65, the increased energy supply to the fuel and oxidizer pumps with higher start tank pressure increased the start transient pump discharge pressures. The resulting increase in oxidizer flow rate to the main chamber reduced the thrust chamber ignition time by 24 msec. The gas generator outlet temperature initial peak was 1680°F on firing 34B with the higher start tank pressure and slightly lower at 1620°F on firing 35B with lower start tank pressure. (This same trend of increasing gas generator outlet initial temperature peaks with higher start tank pressures was experienced on firings J4-1801-8B and J4-1801-8D, Ref. 6.) These firings exhibit a 0.5°F increase in gas generator outlet temperature, initial peak, for 1-psi increase in start tank pressure. A gas generator second temperature peak of 1920°F occurred on firing 34B and 1639°F on firing 35B, a 2.3°F increase per 1-psi increase in start tank pressure. The main oxidizer valve second-stage initial movement time was delayed on firing 34B because of a higher oxidizer pump discharge pressure which increased hydraulic torque and caused a higher second peak.

A comparison of start transient fuel pump head-flow performance for the two firings is shown in Fig. 66. The stall margin was conservative in each case, but more so on firing 34B with higher start tank pressure because of a higher fuel pump discharge pressure and increased fuel flow.

Engine vibrations (VSC) were recorded for a short time on each firing. Approximately 7 and 5 msec of vibrations were observed on firings 34B and 35B, respectively.

4.2.4 Fuel Pump NPSH Effects on Start Transient

Firings 34C and 36C were conducted with almost identical start conditions except that fuel pump NPSH was 310 ft on firing 34C and 710 ft on firing 36C. The prevalve start sequence was different for the two firings (auxiliary on firing 34C and normal on firing 36C), but at engine start all conditions were comparable. A comparison of selected parameters during the start transient is presented in Fig. 67. The fuel pump head-flow coefficient data presented in Fig. 67e indicate less pronounced pump cavitation tendencies during the start transient of firing 36C. The initial gas generator outlet temperature was 2015 and 2140°F, respectively, on firings 34C and 36C.

Normally, a higher peak would be expected with lower NPSH valves. However, in the present case, the higher gas generator peak temperature occurred with the higher of the two NPSH valves. The reason for this unexpected trend is not readily apparent.

Thrust chamber ignition occurred at t_0 + 0.982 and 0.980 sec on firings 34C and 36C, respectively. The main oxidizer valve second-stage ramp began 20 msec sooner on firing 36C. Engine vibrations (VSC) were recorded for 47 msec on firing 34C and for 36 msec on firing 36C. Fuel pump start transient performance for firings 34C and 36C is compared with the stall inception line in Fig. 68. A more conservative stall margin was observed on firing 36C.

4.2.5 S-IVB 6-hr Orbital Coast Restart

Firing 36A was conducted to evaluate engine start transients for a low energy S-IVB 6-hr orbital coast restart. Engine start conditions that provided the low energy included (1) an open propellant utilization valve, (2) a cold thrust chamber body, (3) low start tank energy, and (4) cold turbine hardware. Selected parameters during engine start are presented in Fig. 38. Engine thrust chamber pressure buildup time was extremely slow; main-stage pressure switch number 2 was actuated at t_0 + 2.121 sec, and a 550-psia chamber pressure was attained at t_0 + 2.800 sec, the slowest chamber pressure buildup observed for J-2 engine testing at AEDC to date. The gas generator outlet temperature peaked at 880°F during the initial start transient and is the minimum start transient temperature peak observed to date during testing at AEDC. A direct comparison of firing 36A with previous S-IVB 6-hr restarts in other test series would be invalid because of changes made in the gas generator propellant supply line orifices.

A start transient fuel pump head-flow performance for firing 36A is presented in Fig. 39. The minimum stall margin, which occurred in the high-speed region (approximately 19,000 rpm), was about 600 gpm.

4.2.6 Relief of Thrust Chamber Temperature Launch Constraint-Partial Transition Firing 36E

Firing 36E was a 1.14-sec partial transition test conducted to evaluate the effects of a warm thrust chamber body temperature (0 ± 15°F at engine start) on engine start transient (Fig. 54). A 3-sec fuel lead preceded the firing and, start tank discharge valve solenoid energized, the average thrust chamber body temperature was -91°F. The minimum fuel pump low level stall margin, which would be one of the most critical

items with a warm thrust chamber, was about 1200 gpm (Fig. 55) as measured along a constant pump speed line. This was in the low-speed region at about 12, 000 rpm during start tank discharge. This transition firing was one of a series of tests with warmer thrust chambers; as a consequence of the conservative stall margin obtained during this firing, the effects of warmer thrust chambers will be evaluated in future tests.

4.3 ENGINE STEADY-STATE PERFORMANCE

Selected steady-state engine performance values (see Appendix IV for method of calculations) for all 32.5-sec duration firings are presented in Table VIII. Since there was no engine reorificing during this series of tests, all performance values compared reasonably well. Probably the most significant variation noted was fuel and oxidizer turbine efficiencies. Fuel and oxidizer turbine efficiencies were 1.4 and 2.8 percent, respectively, higher on test 36 than the lowest values calculated for tests 34 and 35.

4.4 POST-TEST INSPECTION

4.4.1 J4-1801-34

A post-test inspection indicated no apparent erosion of the augmented spark igniter chamber. A broken connector to an accelerometer caused an erroneous excessive engine vibration cutoff on firing 34C.

4.4.2 J4-1801-35

The engine pneumatic regulator was replaced after test 35 and the faulty regulator returned to the engine manufacturer for inspection. The inspection revealed that improper operation was caused by a leaky diaphragm in the regulator.

A small particle (Fig. 69) was removed from a fuel annulus of the main injector after test 35. This particle had the appearance of a small diameter copper wire.

4.4.3 J4-1801-36

Post-test leak checks of the fuel turbopump indicated excessive leakage of the intermediate and turbine seals (greater than 10, 000 scim) and were replaced. One of the gas generator outlet temperature sensors was found eroded and was also replaced.

SECTION V
SUMMARY OF RESULTS

The results of the 12 firings of the Rocketdyne J-2 rocket engine conducted on March 27 and April 2 and 10, 1968, in Test Cell J-4 are summarized as follows:

1. Thrust chamber temperature effect on engine transient operation, for S-IVB first burns and 80-min orbital coast restart simulation firings, was investigated. For this series of tests, it was determined that each 1°F reduction in thrust chamber temperature (temperature ranged from -91 to -358°F for first burns and -200 to -362°F for 80-min restarts) resulted in 1.5 and 1.6°F increase in the gas generator outlet temperature initial peak for first burns and 80-min restarts, respectively.
2. For S-IVB 80-min restart tests, a 4.3°F increase in the gas generator outlet temperature initial peak was observed for each 1°F reduction in start tank temperature (for start tank temperatures of -216 and -268°F).
3. Start tank pressure increases (pressure values of 1174 and 1294 psia) resulted in higher gas generator outlet temperature peaks and faster thrust chamber ignition for S-IVB 80-min restarts. The firings investigated exhibited a 0.5 and 2.3°F increase, respectively, in the initial and second gas generator outlet temperature peak for each 1-psi increase in start tank pressure.
4. Two firings were investigated to determine effects of fuel pump NPSH on engine start transient.
5. A gas generator outlet temperature transient peak of 880°F was recorded for an S-IVB 6-hr orbital coast restart and is the minimum recorded to date. Chamber pressure buildup time to 550 psia required 2.8 sec, the longest to date.
6. A partial transition firing (36E) was conducted with a thrust chamber throat temperature requirement of 0 ± 15 deg at engine start with a 3-sec fuel lead. A conservative fuel pump stall margin was observed for this firing.
7. Post-test inspection indicated no apparent deterioration of the augmented spark igniter chamber during this series of tests.
8. A small particle was removed from a fuel annulus of the main injector after test 35. The particle had the appearance of a small diameter copper wire.

REFERENCES

1. Dubin, M., Sissenwine, N., and Wexler, H. U. S. Standard Atmosphere, 1962. December 1962.

2. Kunz, C. H. and Counts, H. J. "Altitude Developmental Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1801-28 through J4-1801-33)." AEDC-TR-68-160, October 1968.

3. "J-2 Rocket Engine, Technical Manual Engine Data." R-3825-1, August 1965.

4. Test Facilities Handbook (7th Edition). "Large Rocket Facility, Vol. 3." Arnold Engineering Development Center, July 1968.

5. Franklin, D. E. "Altitude Developmental Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Test J4-1801-02." AEDC-TR-67-192 (AD824273). December 1967.

6. Simpson, J. N. and Tinsley, C. R. "Altitude Developmental Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Test J4-1801-08)." AEDC-TR-67-240 (AD825574L), January 1968.

APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION
IV. METHODS OF CALCULATION (PERFORMANCE PROGRAM)

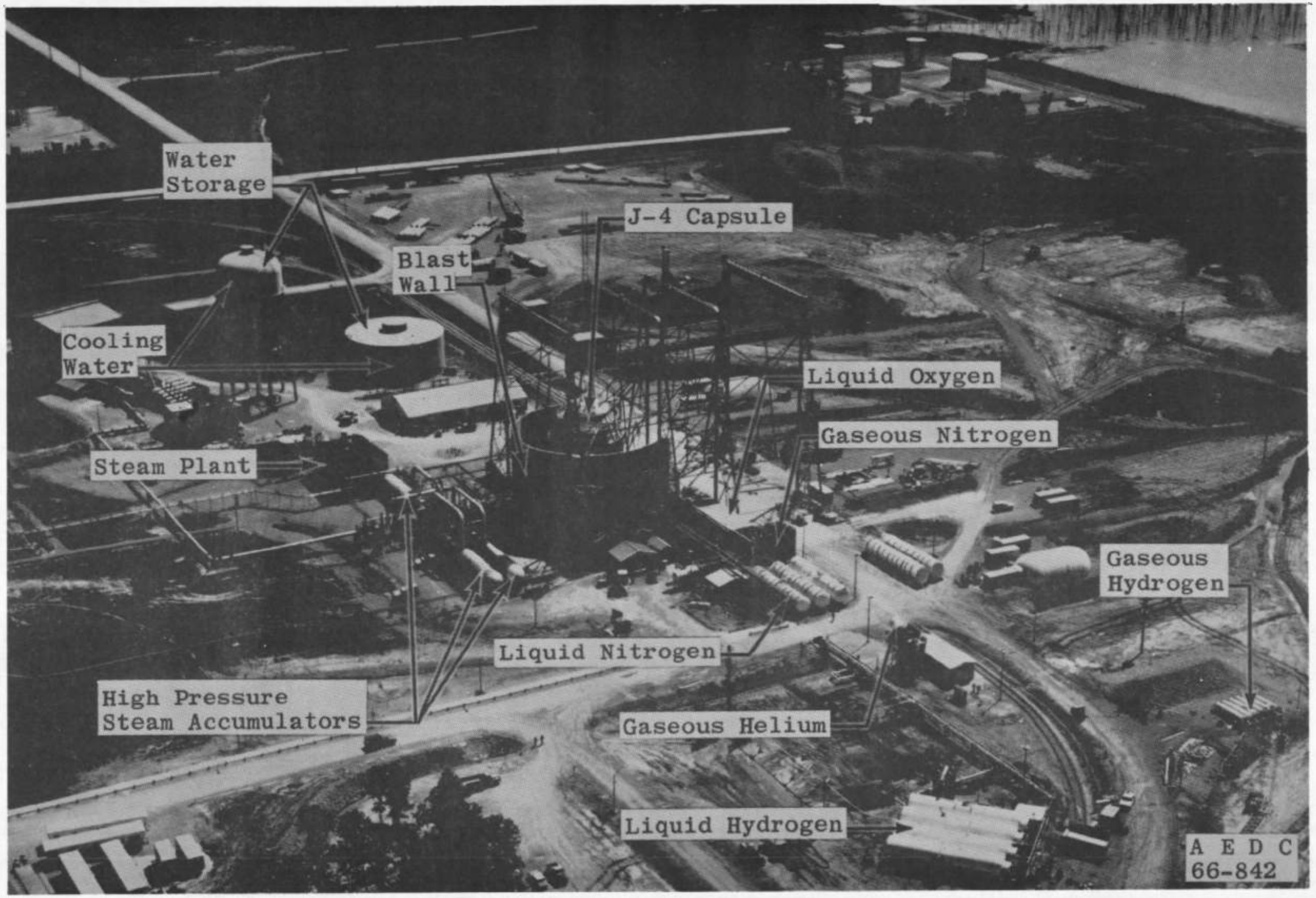


Fig. 1 Test Cell J-4 Complex

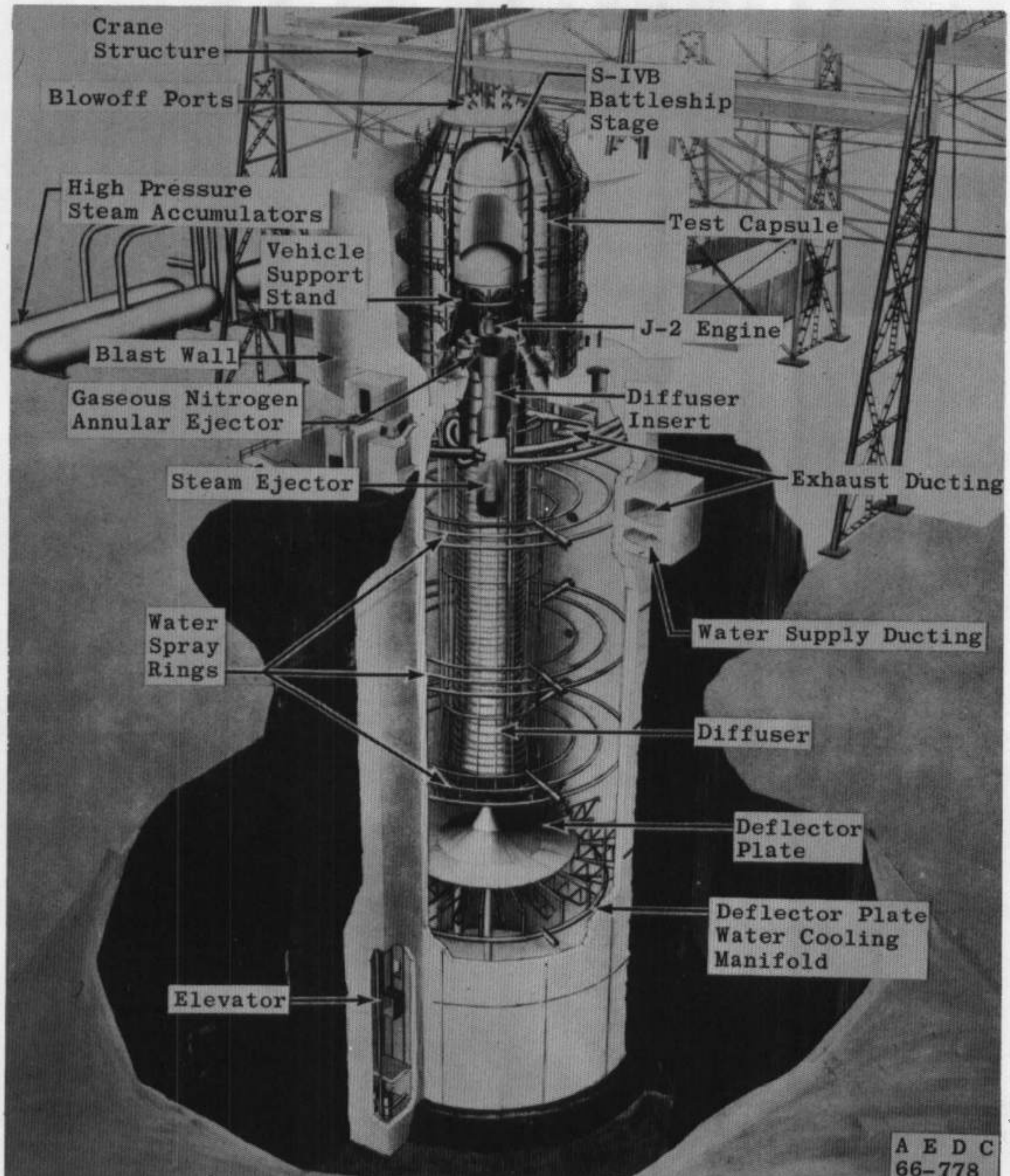


Fig. 2 Test Cell J-4, Artist's Conception

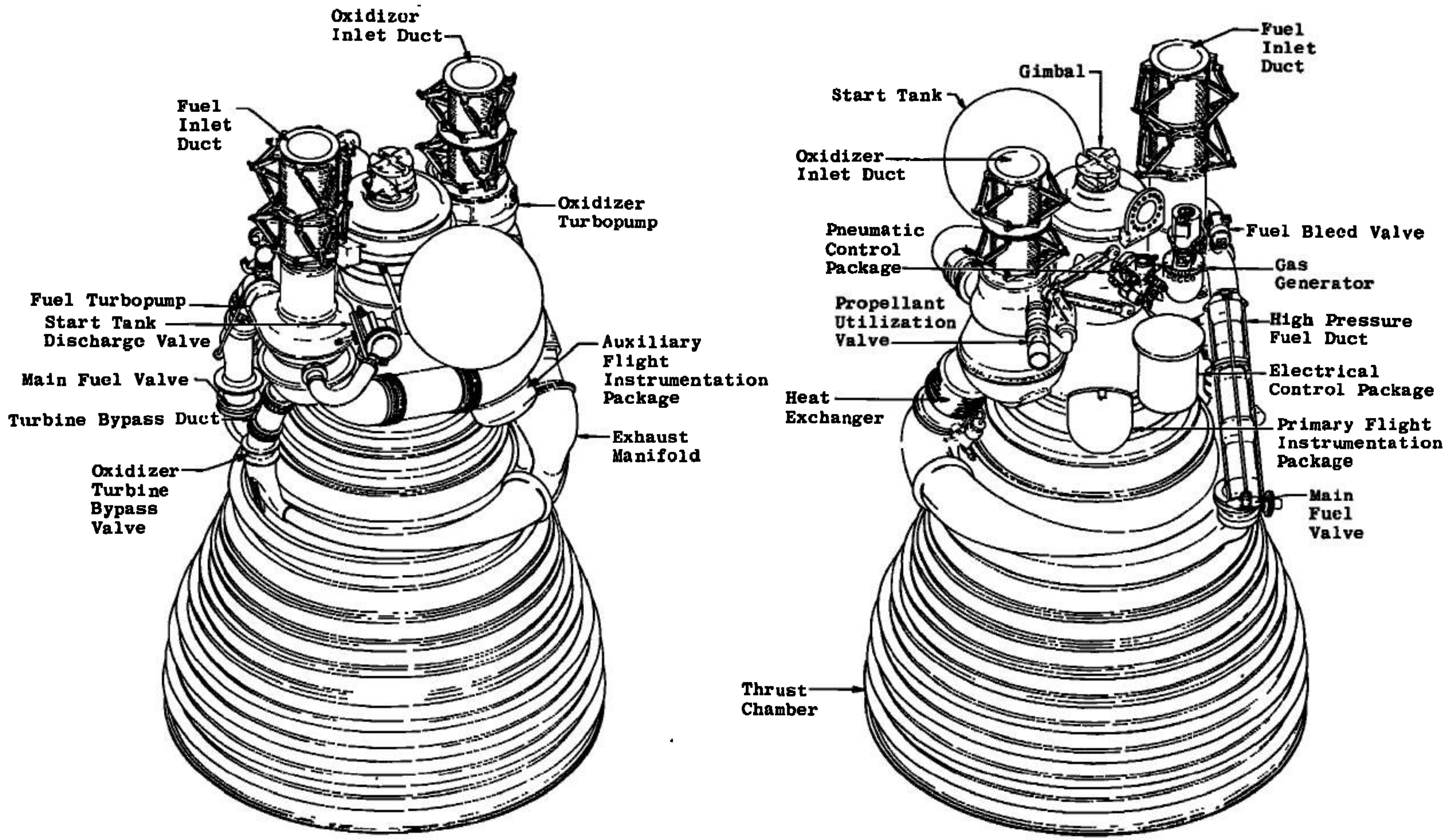


Fig. 3 Engine Details

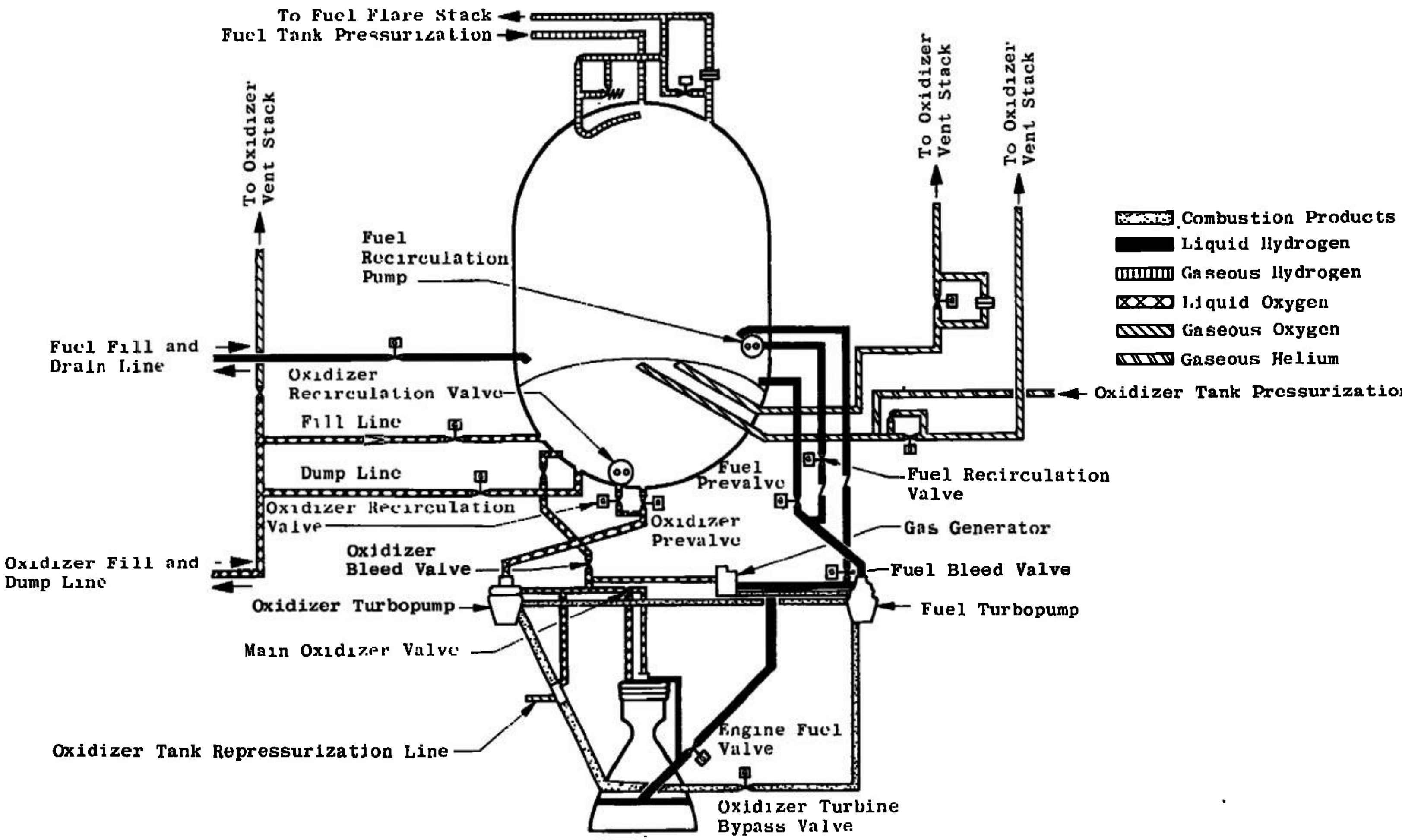


Fig. 4 S-IVB Battleship Stage/J2 Engine Schematic

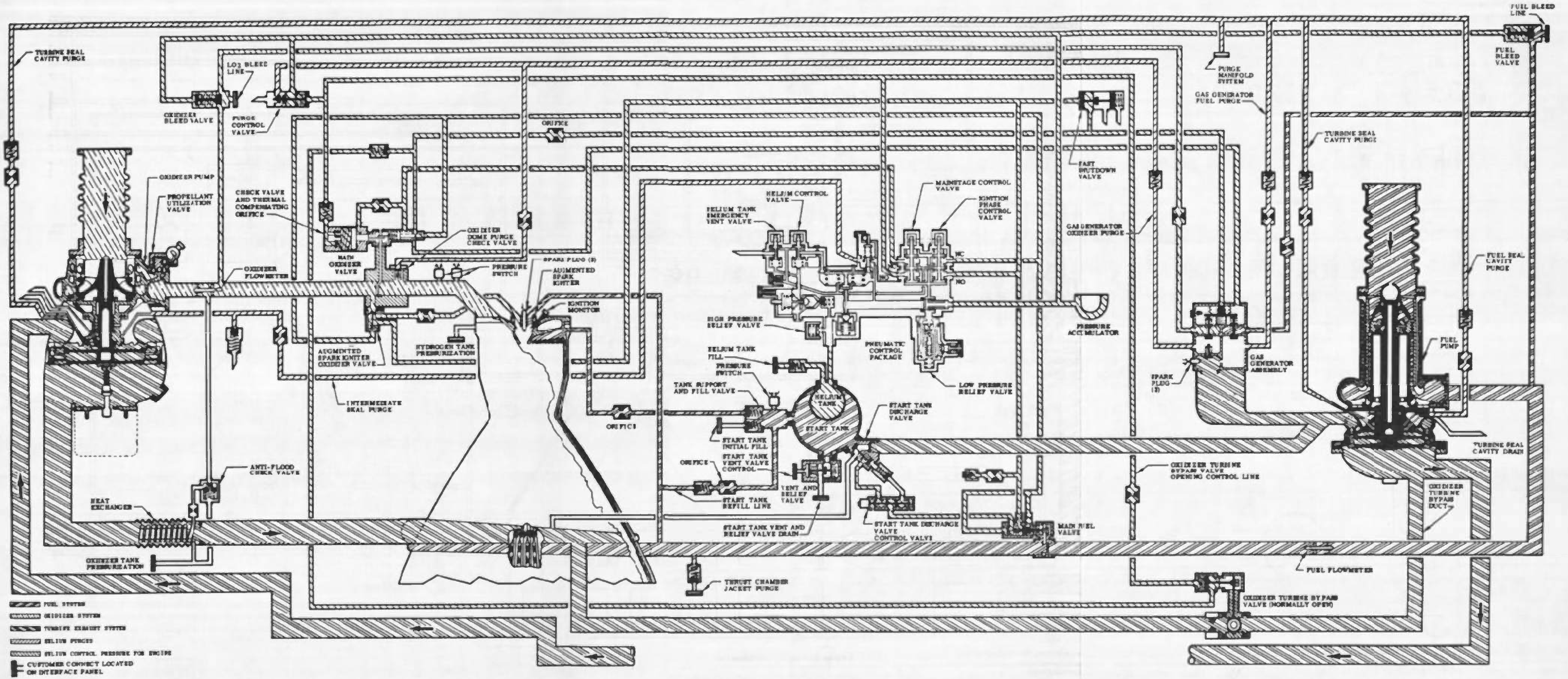


Fig. 6 Engine Schematic

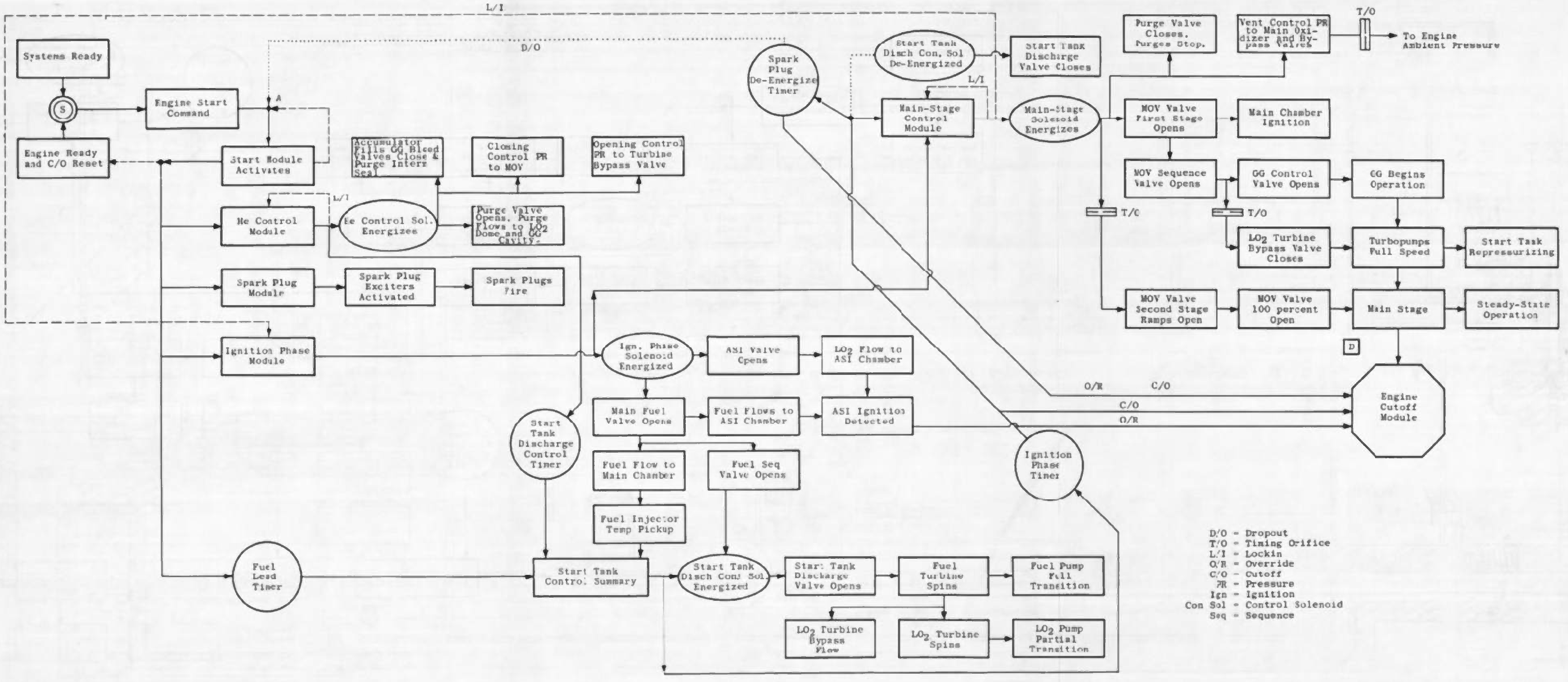
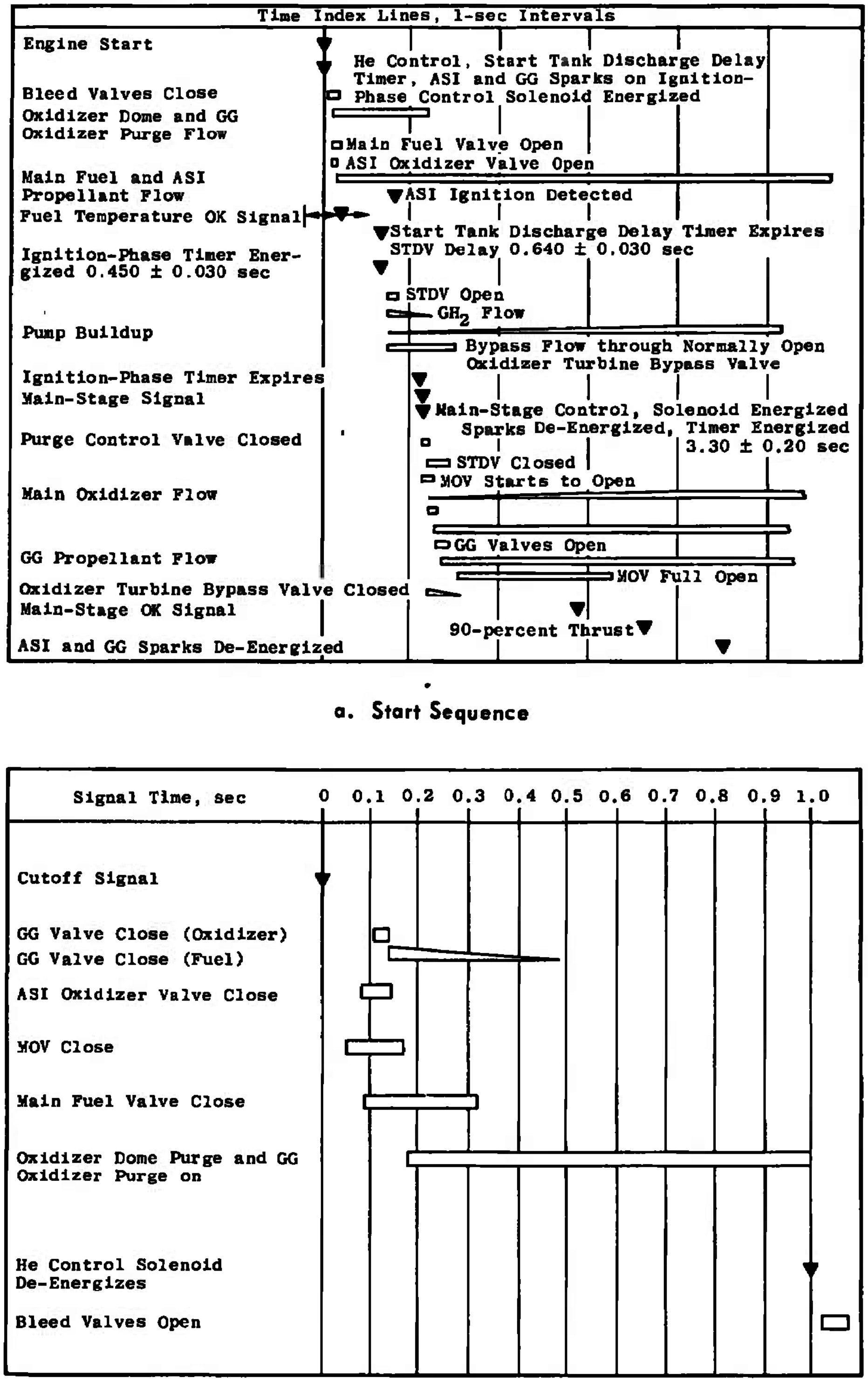


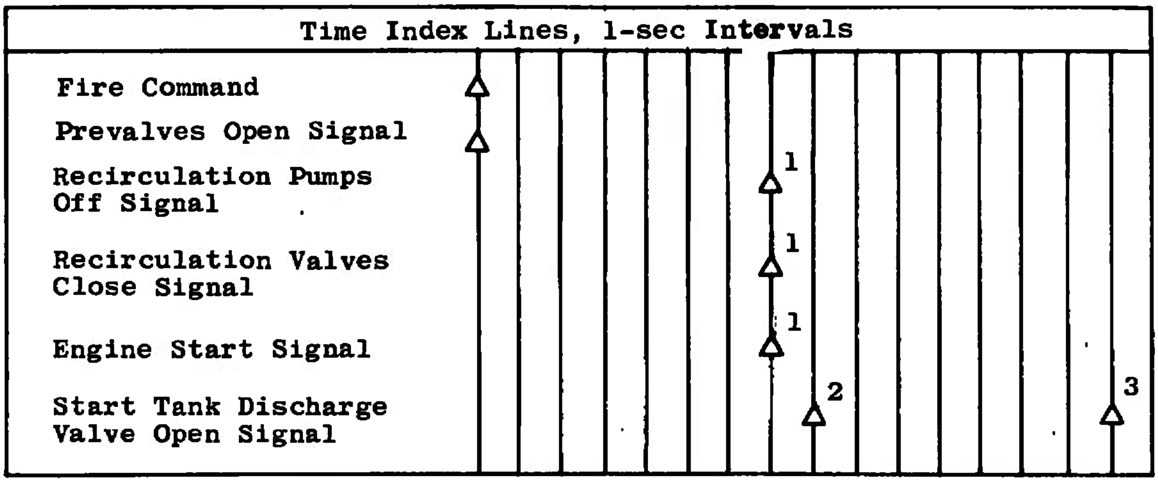
Fig. 7 Engine Start Logic Schematic



a. Start Sequence

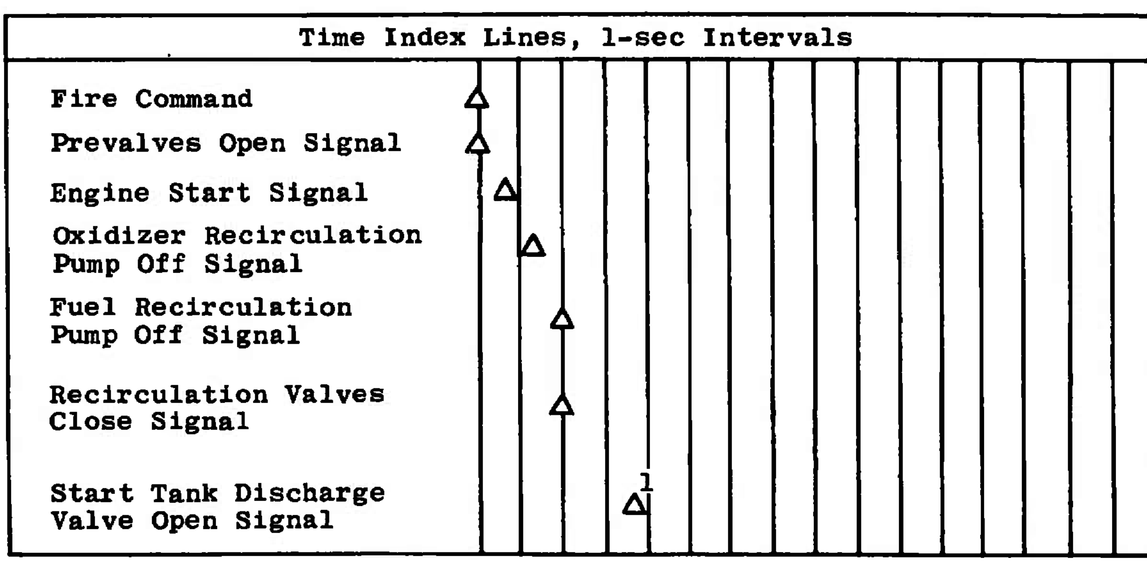
b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence



[1]Nominal Occurrence Time (Function of Prevalves Opening Time)
[2]One-sec Fuel Lead (S-II/S-V and S-IVB/S-IB)
[3]Eight-sec Fuel Lead (S-IVB/S-V and S-IB Orbital Restart)

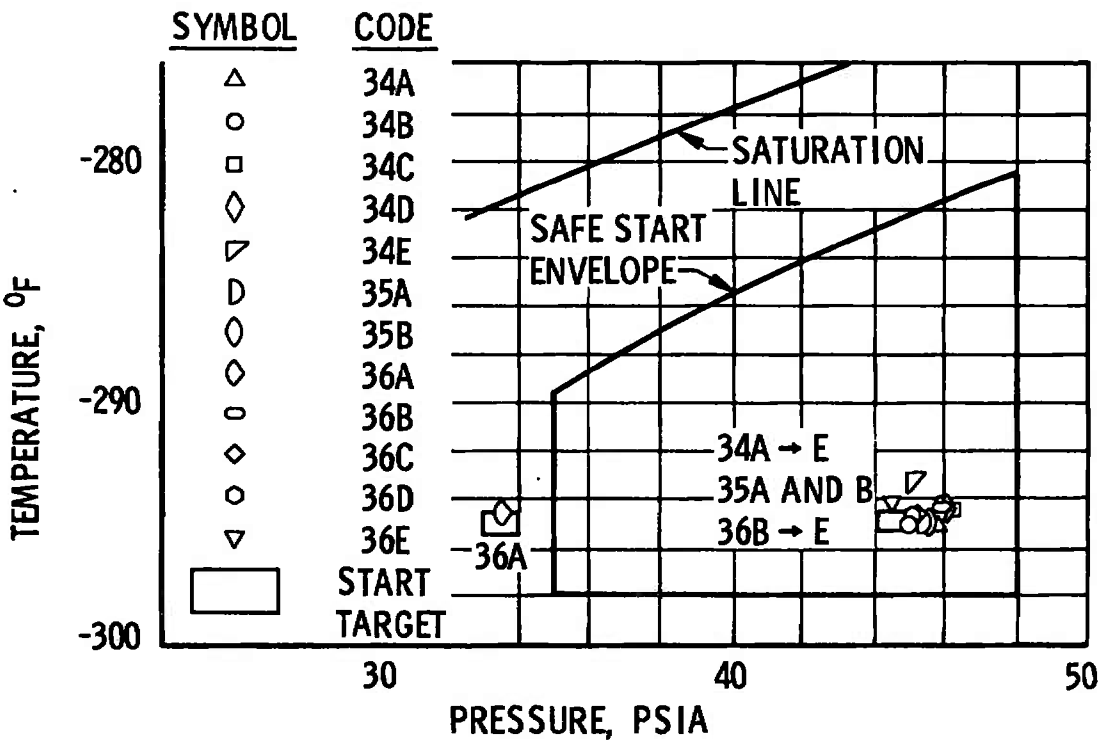
c. "Normal" Start Sequence



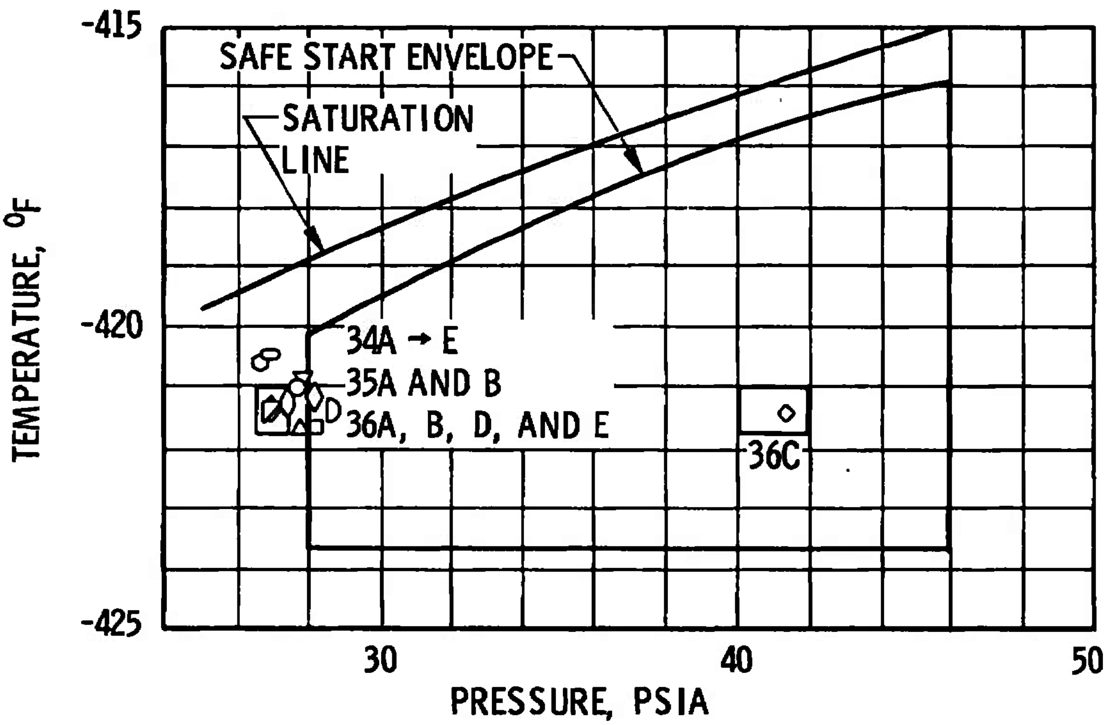
[1]Three-sec Fuel Lead (S-IVB/S-V First Burn)

d. "Auxiliary" Start Sequence

Fig. 7 Concluded

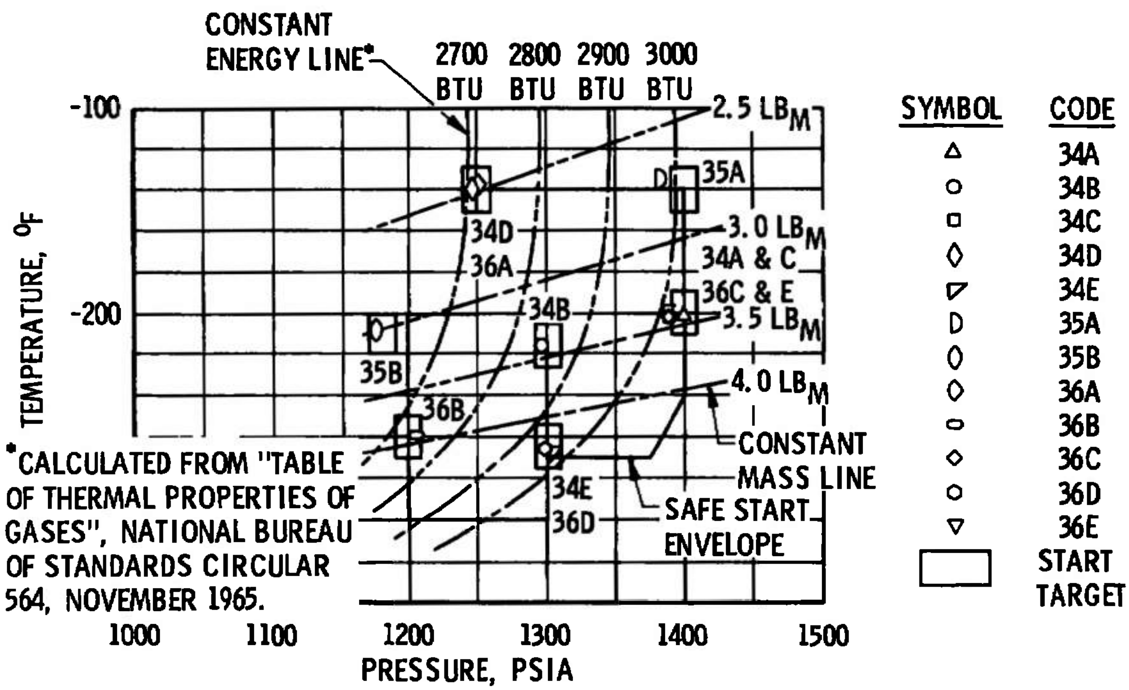


a. Oxidizer Pump Inlet

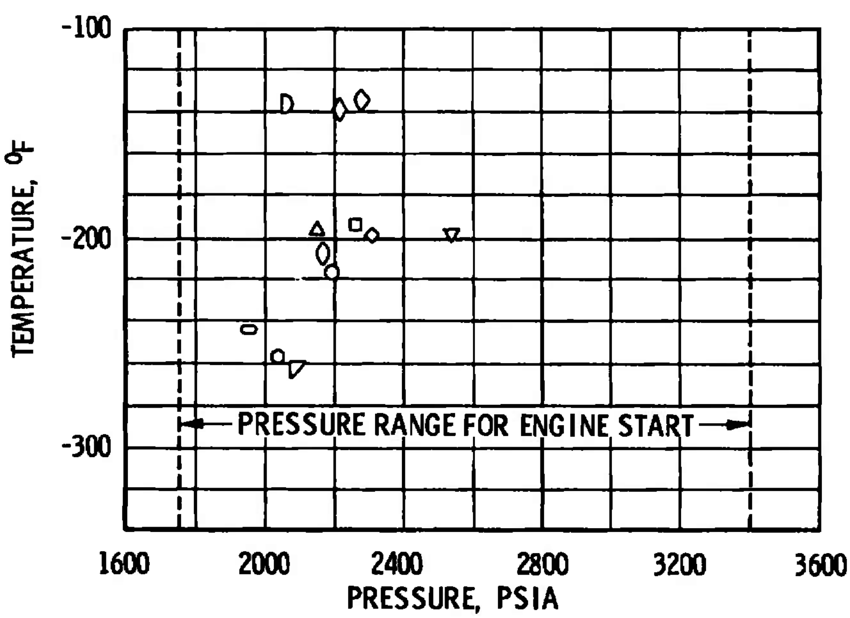


b. Fuel Pump Inlet

Fig. 8 Engine Start Conditions for Pump Inlets, Start Tank, and Helium Tank

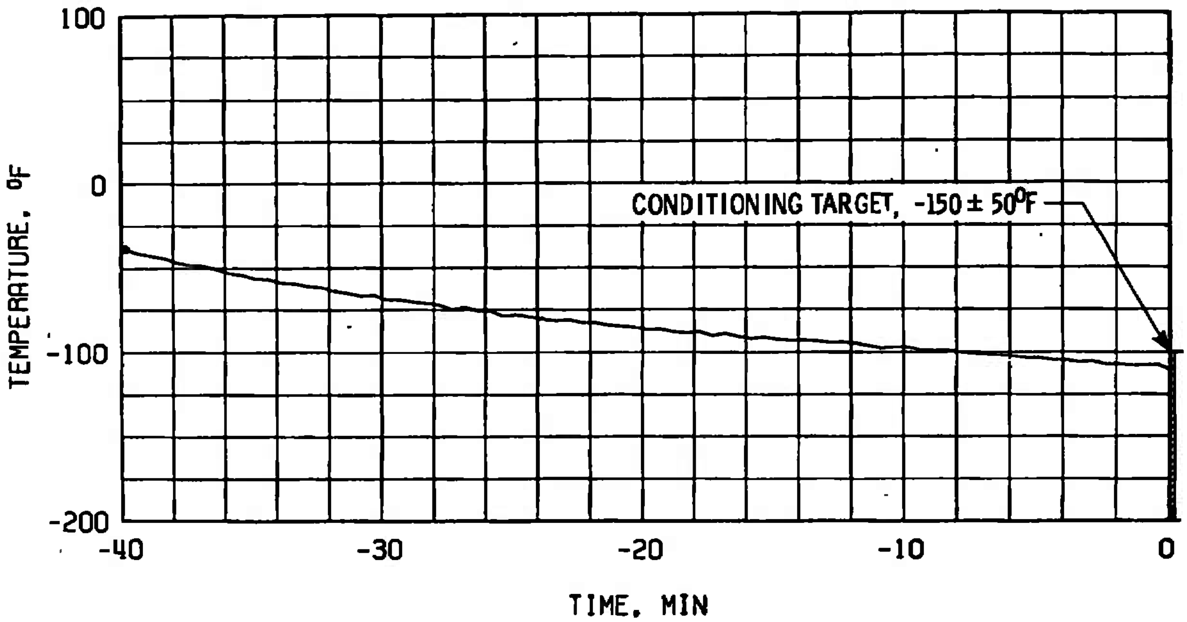


c. Start Tank

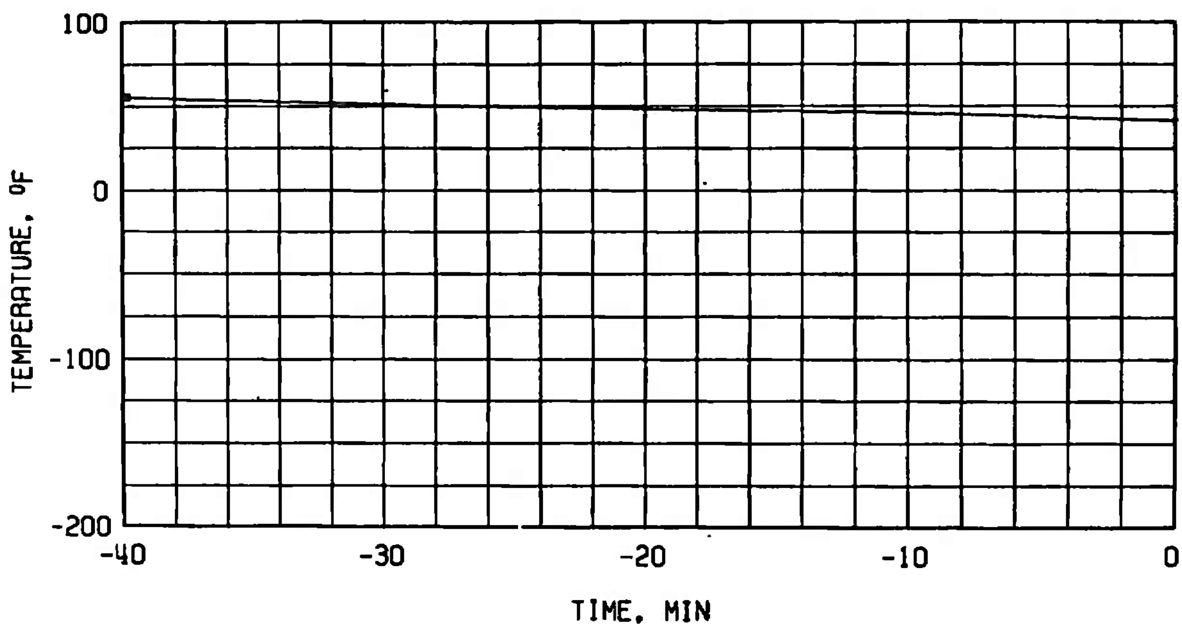


d. Helium Tank

Fig. 8 Concluded

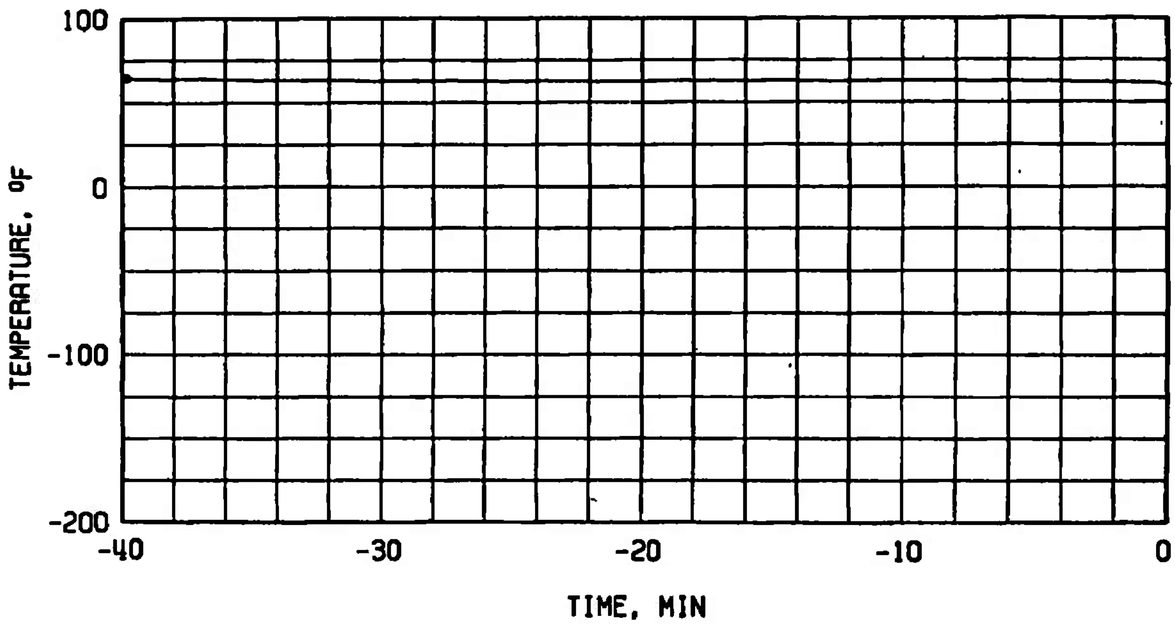


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

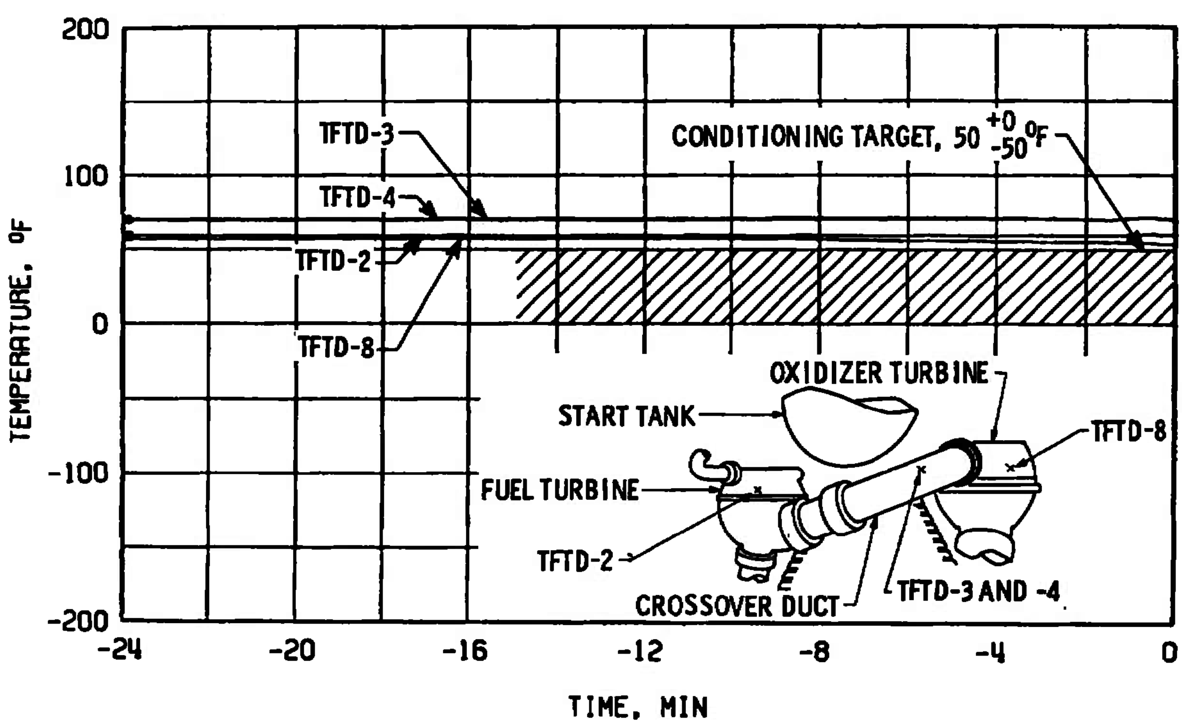


b. Gas Generator Body Temperature, TGGVRS

Fig. 9 Thermal Conditioning History of Engine Components, Firing 34A

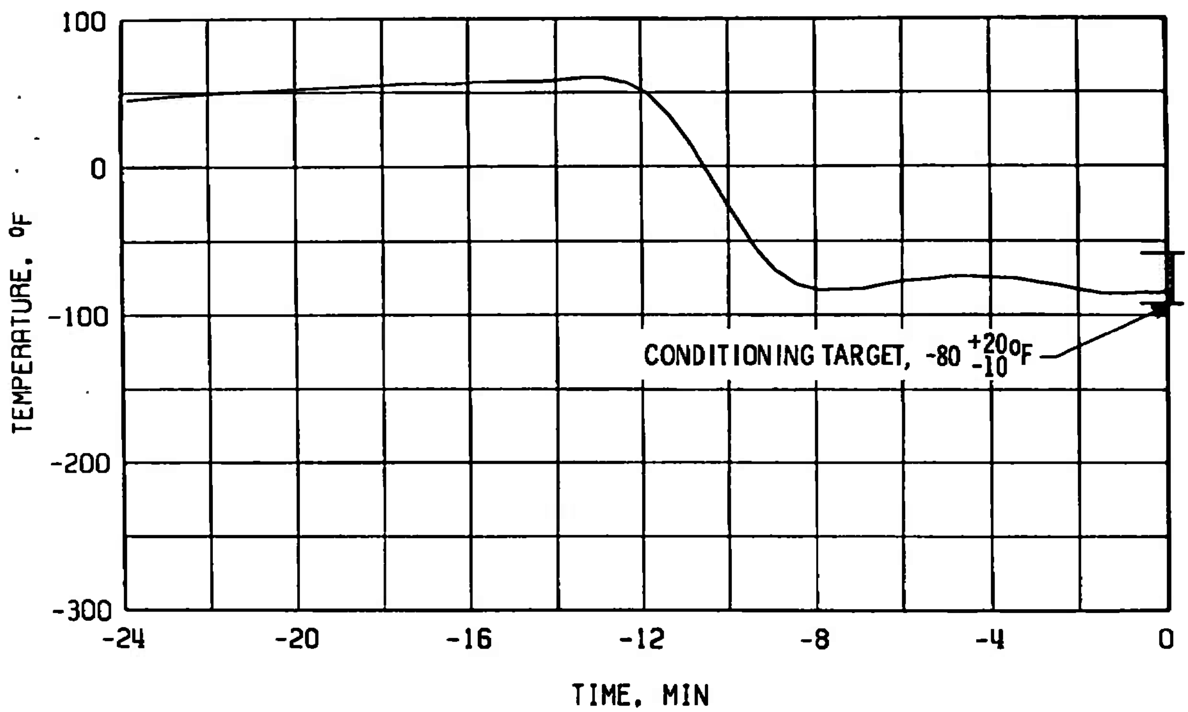


c. Start Tank Discharge Valve Opening Control, TSTDVOC

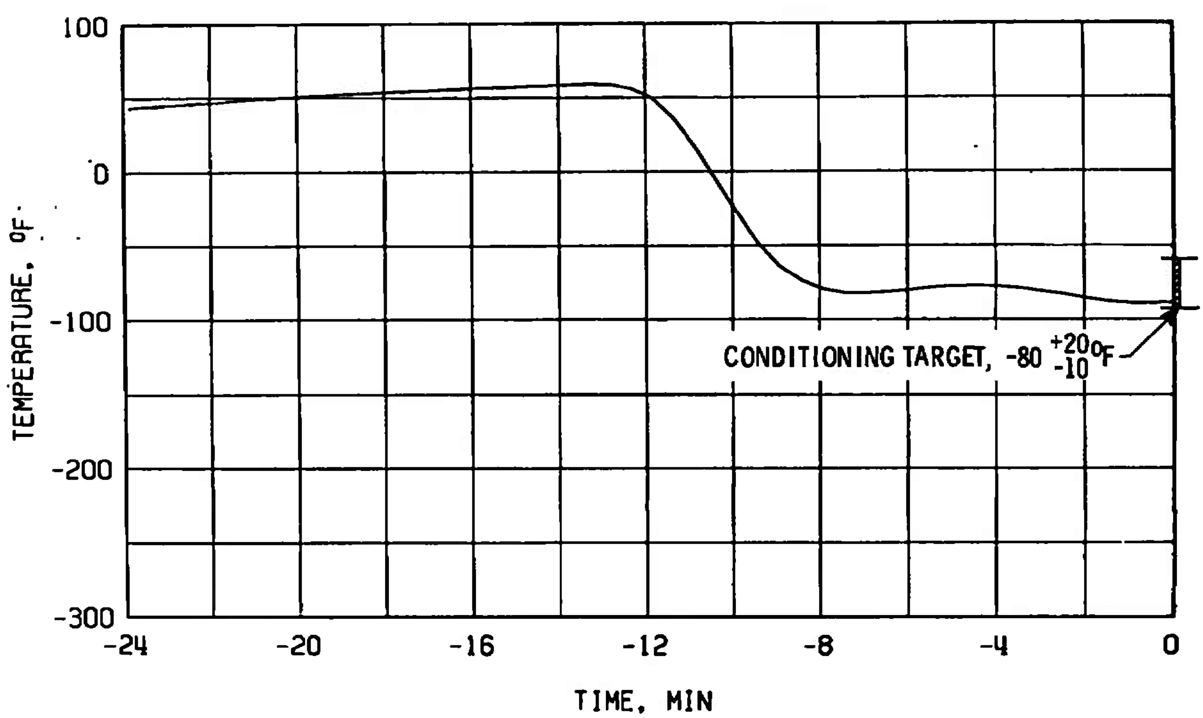


d. Crossover Duct, TFTD

Fig. 9 Continued

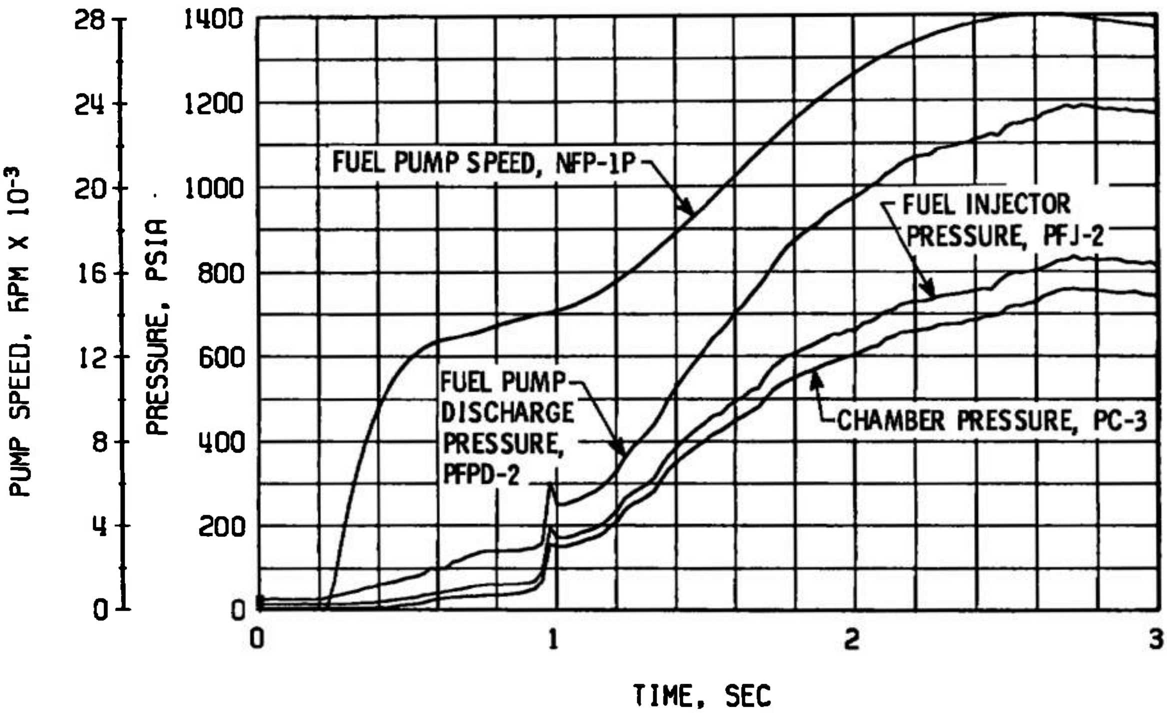


e. Thrust Chamber Throat, TTC-1P

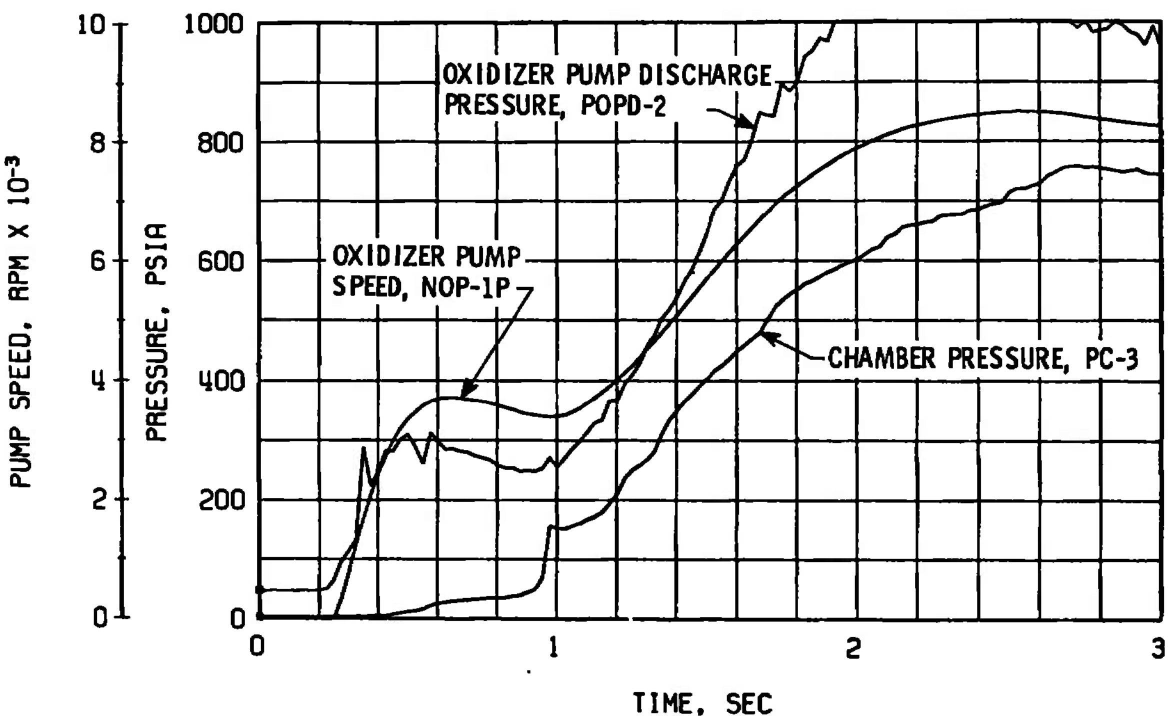


f. Thrust Chamber Throat, TTC-2

Fig. 9 Concluded

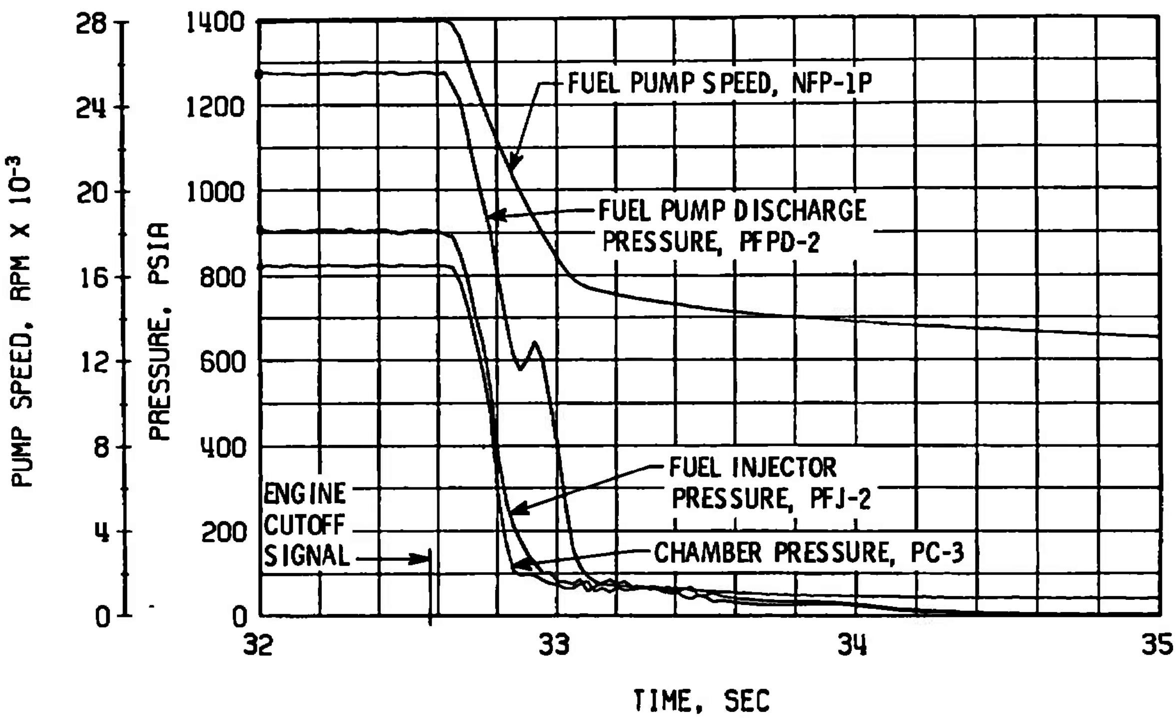


a. Thrust Chamber Fuel System, Start

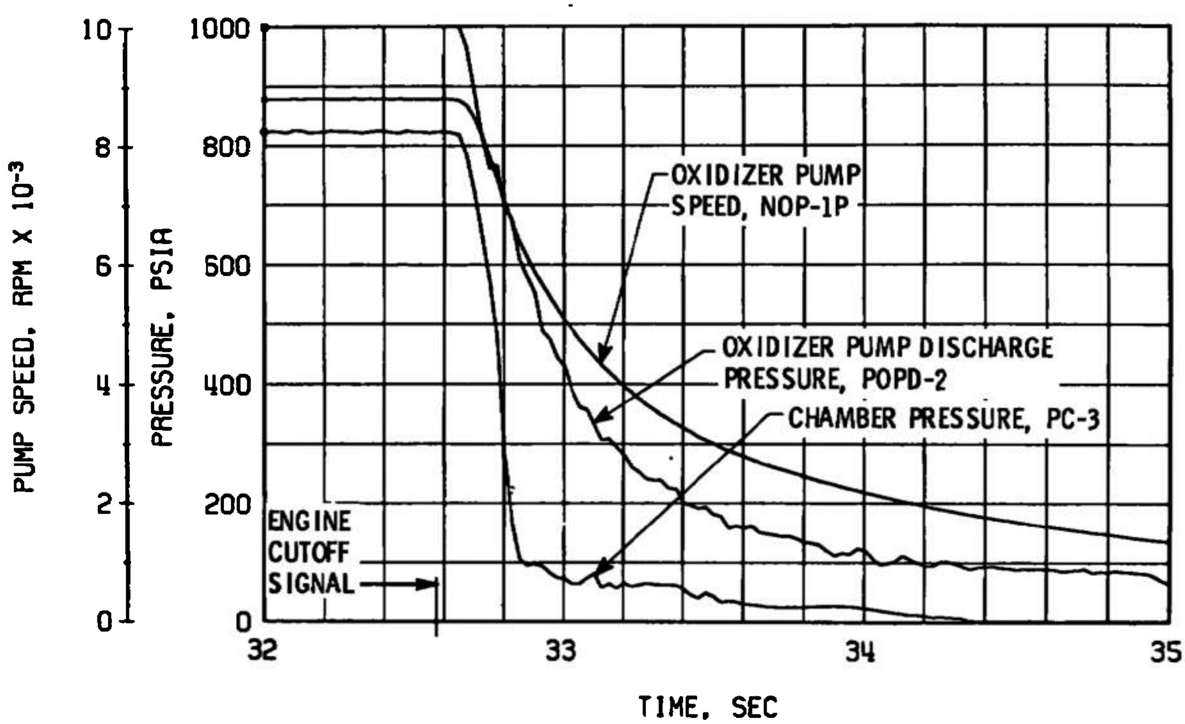


b. Thrust Chamber Oxidizer System, Start

Fig. 10 Engine Transient Operation, Firing 34A

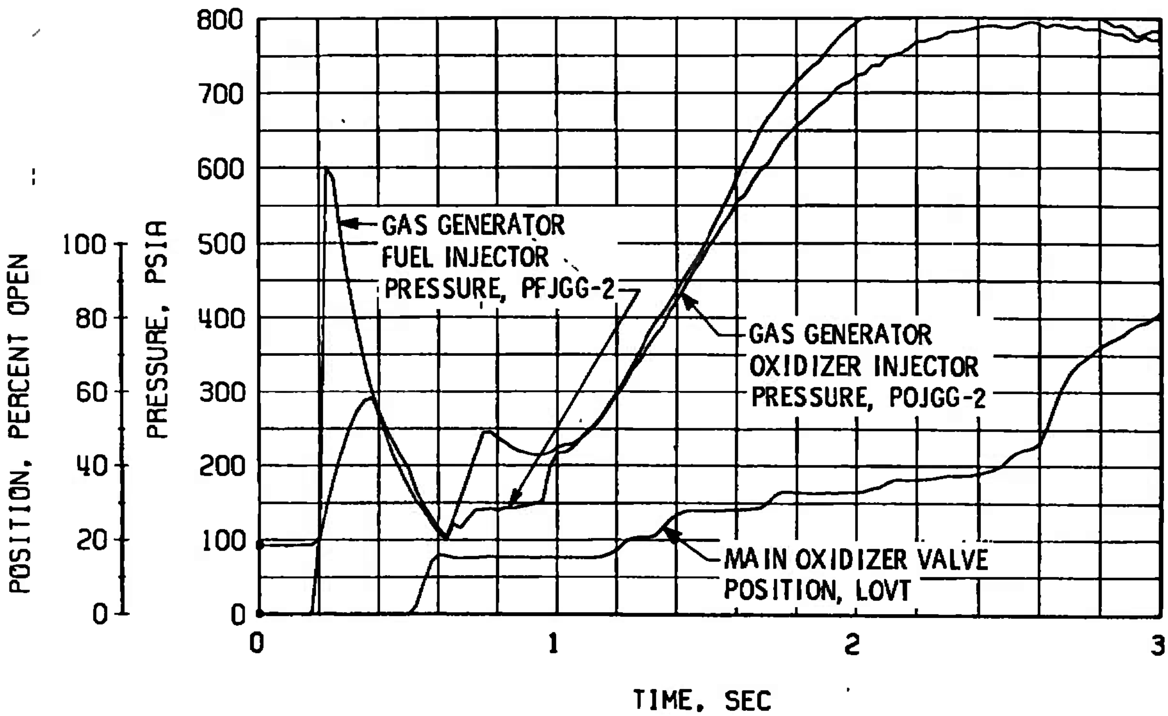


c. Thrust Chamber Fuel System, Shutdown

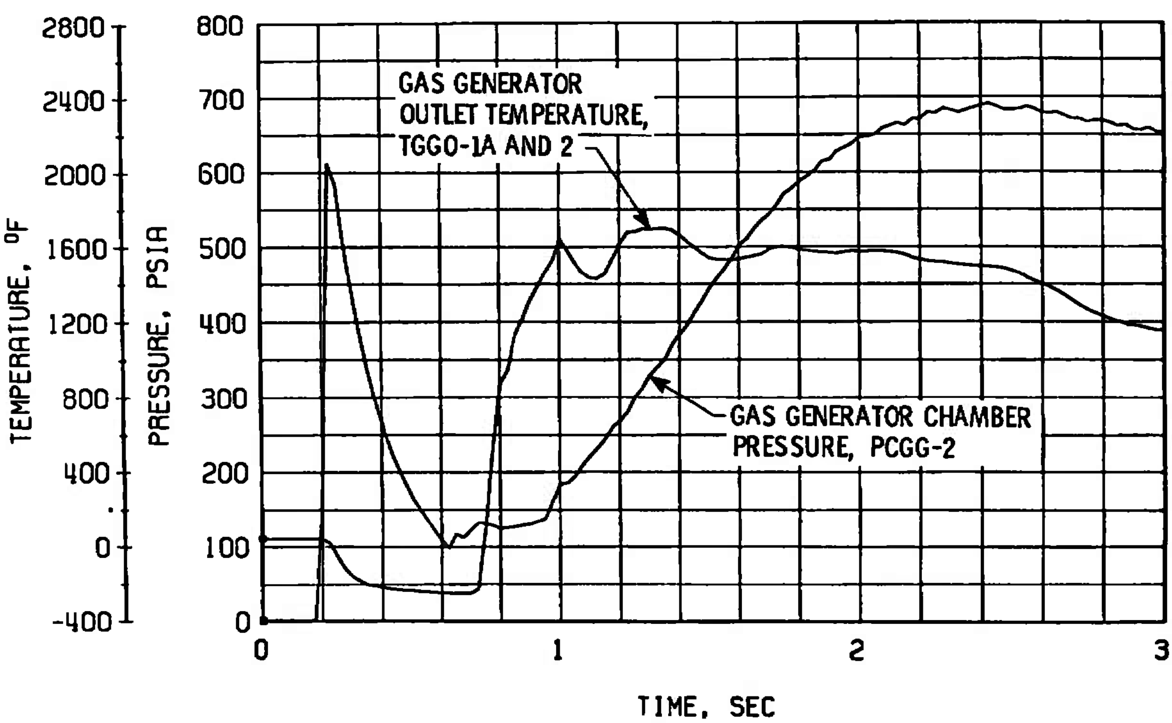


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 10 Continued

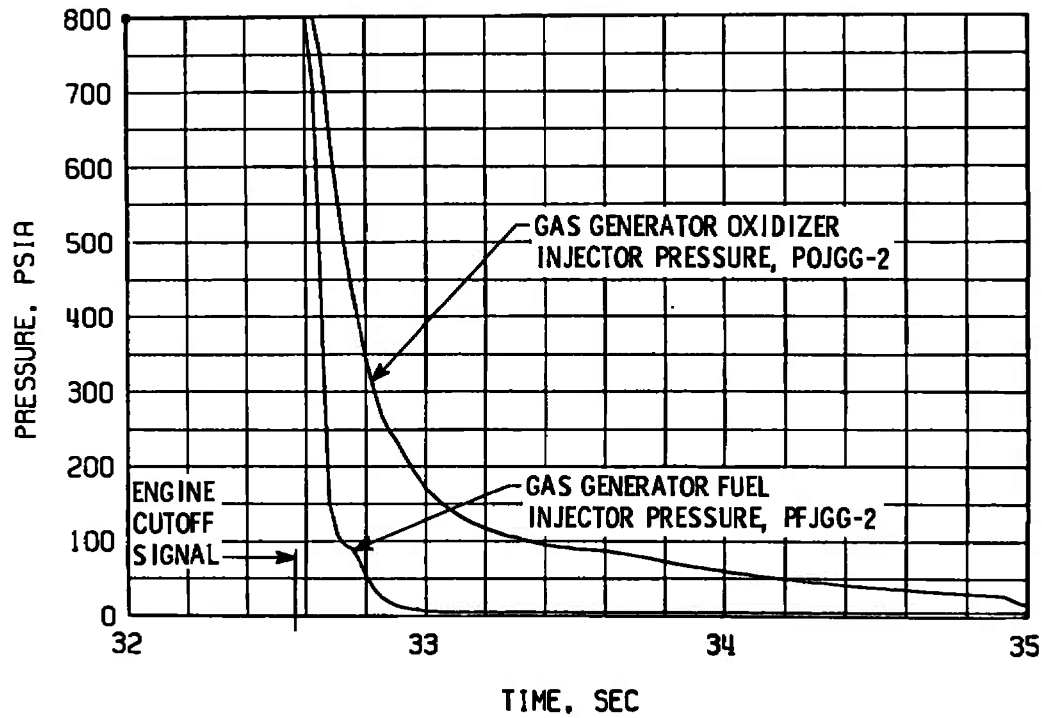


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

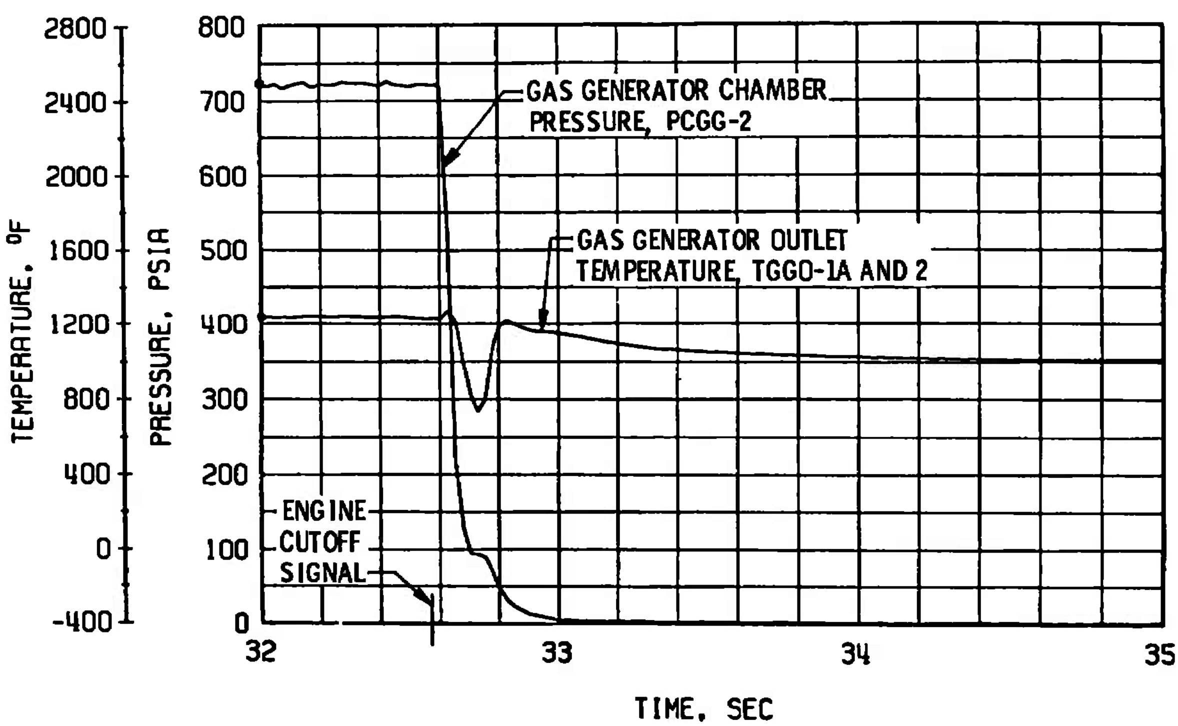


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 10 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 10 Concluded

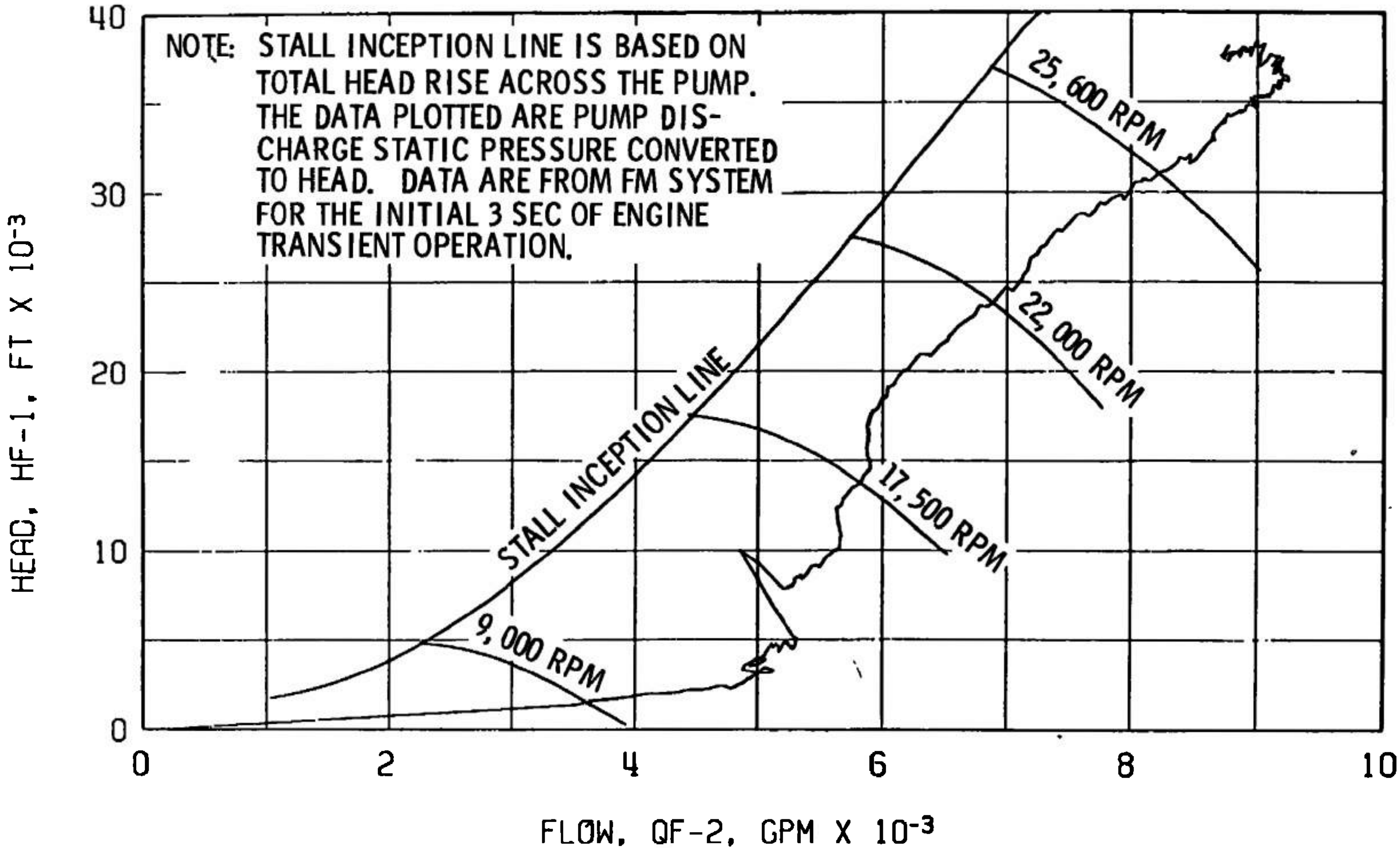


Fig. 11 Fuel Pump Start Transient Performance, Firing 34A

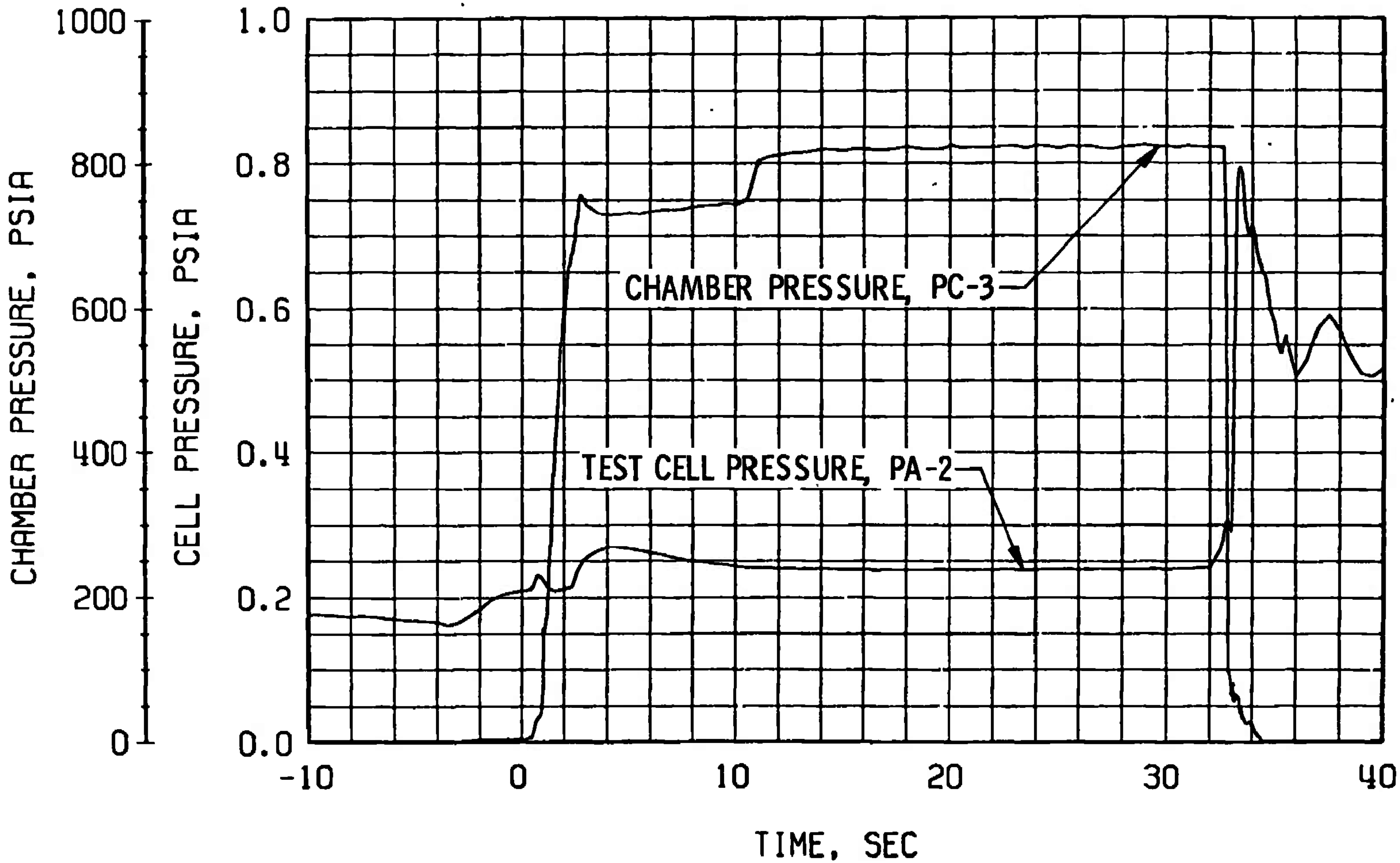
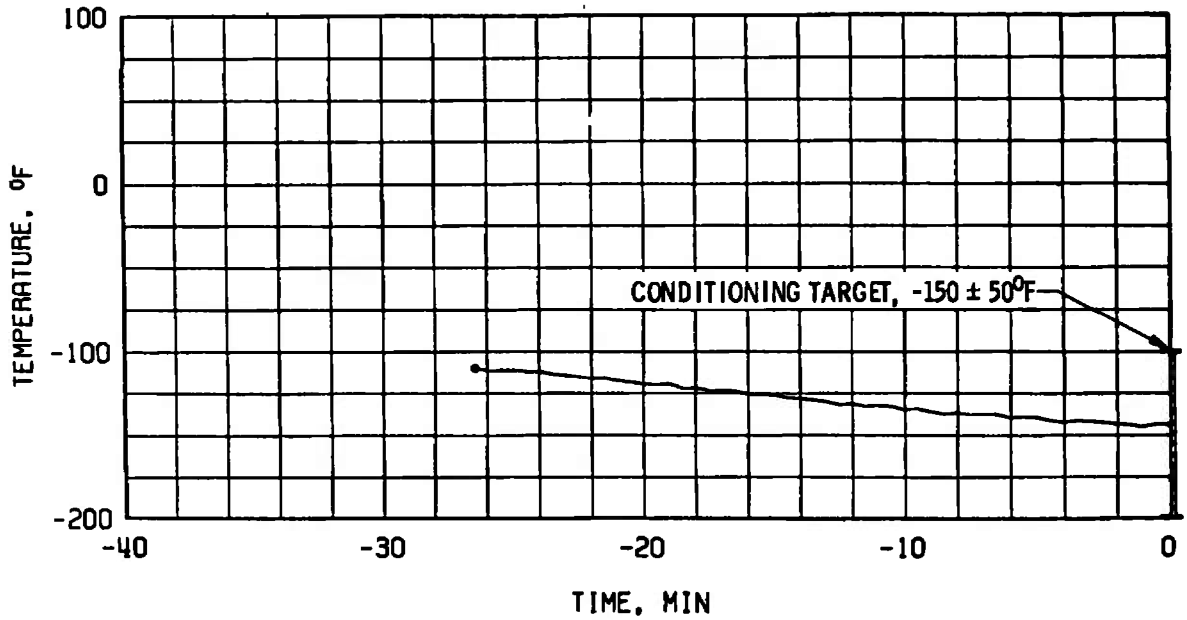
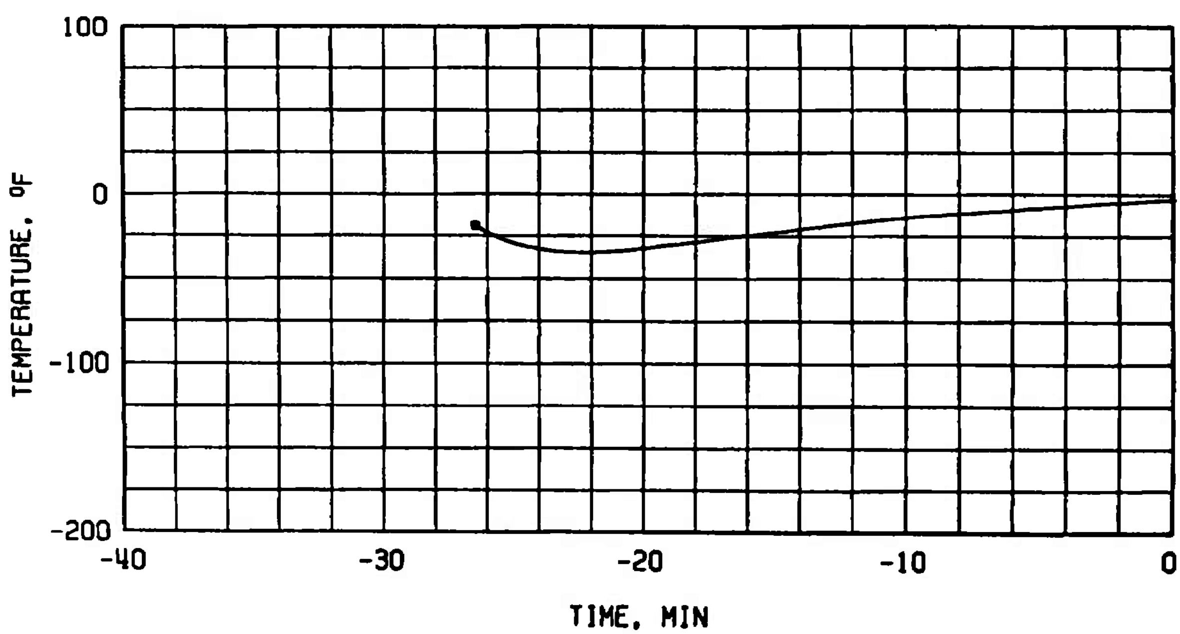


Fig. 12 Engine Ambient and Combustion Chamber Pressure, Firing 34A

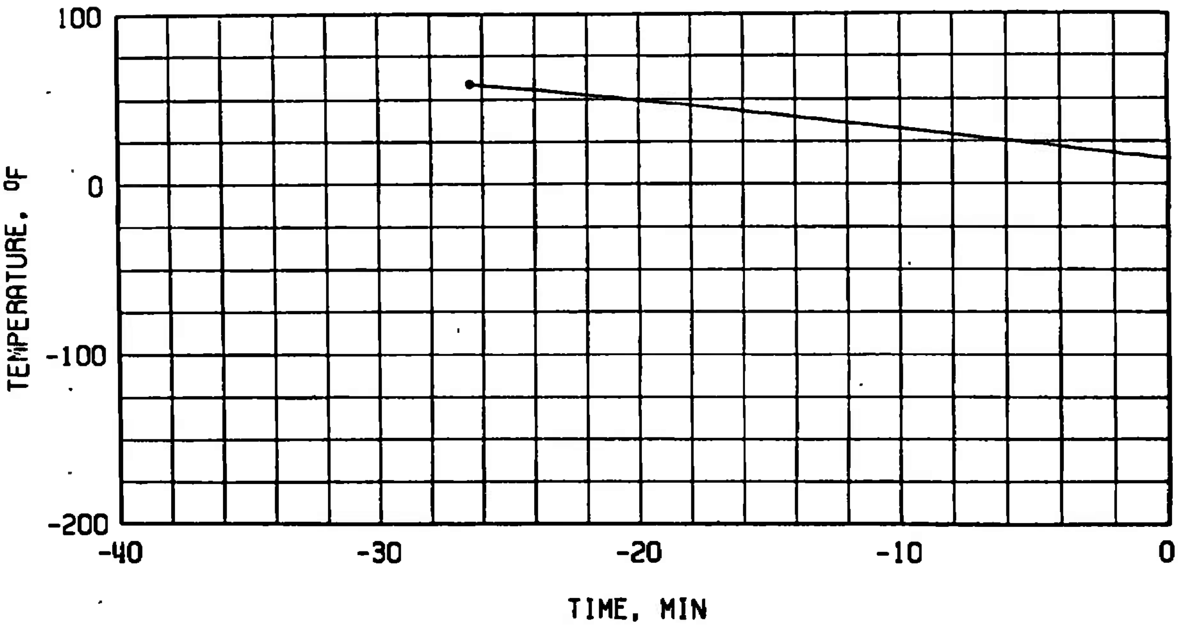


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

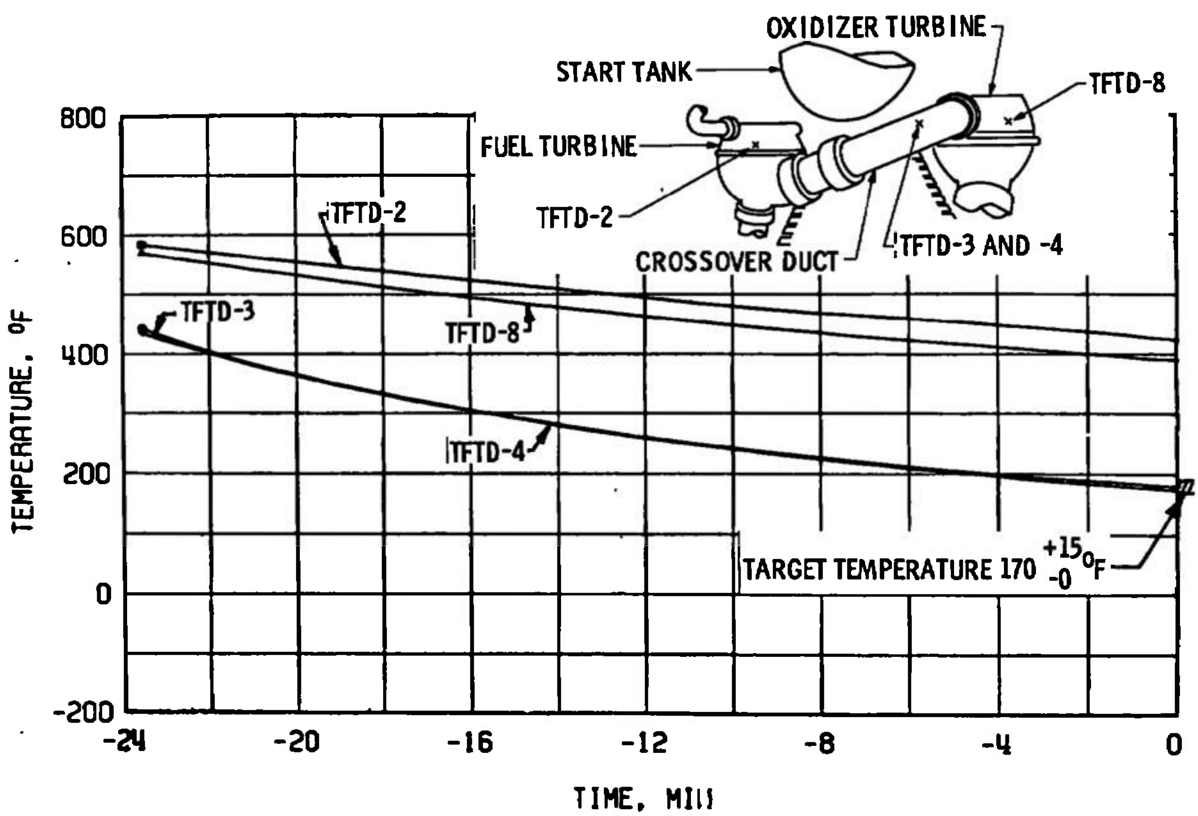


b. Gas Generator Body Temperature, TGGVRS

Fig. 13 Thermal Conditioning History of Engine Components, Firing 34B

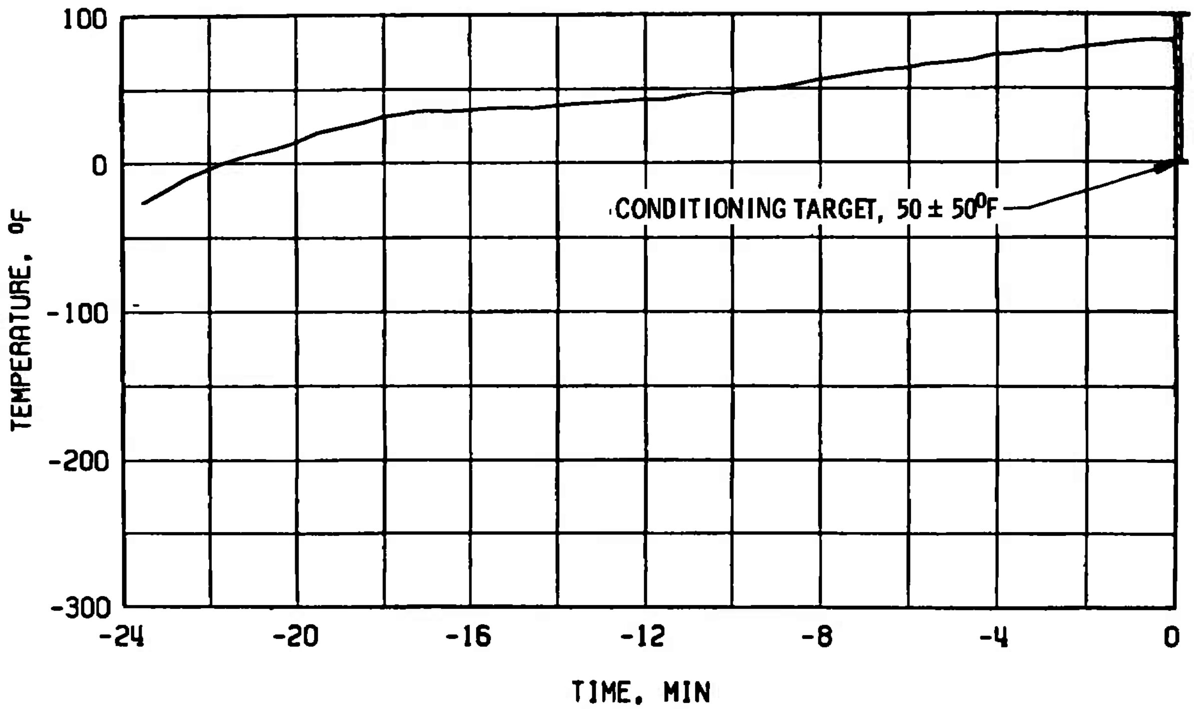


c. Start Tank Discharge Valve Opening Control, TSTDVOC

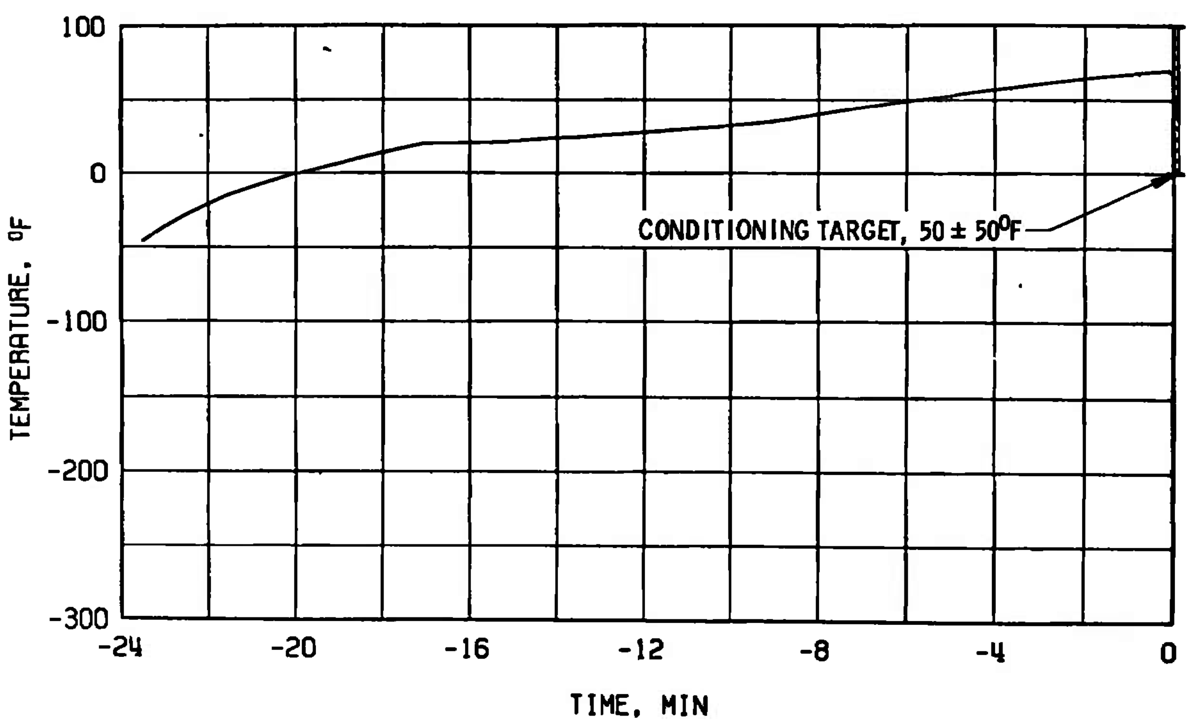


d. Crossover Duct, TFTD

Fig. 13 Continued

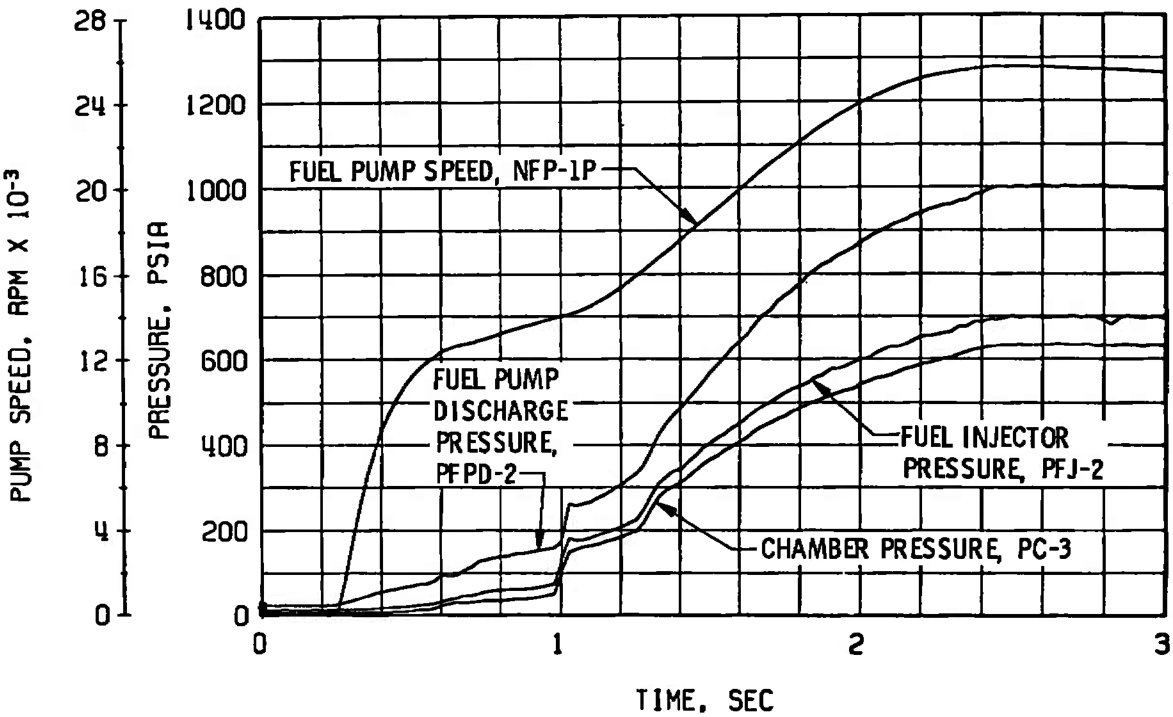


e. Thrust Chamber Throat, TTC-1P

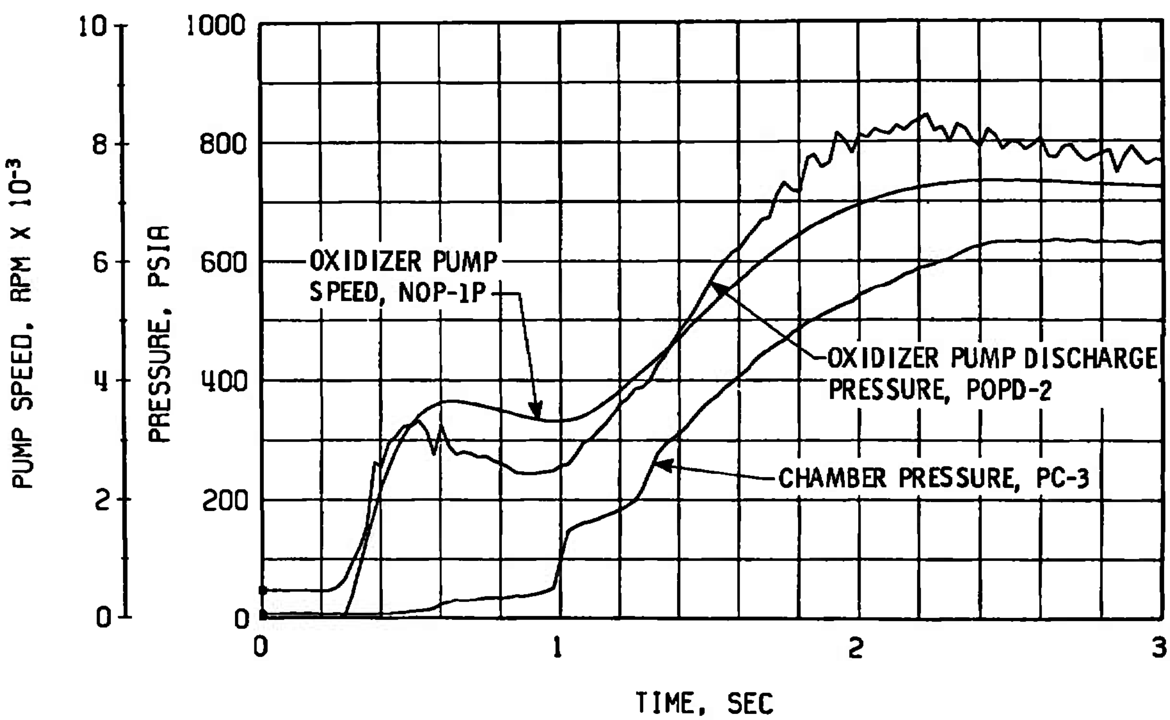


f. Thrust Chamber Throat, TTC-2P

Fig. 13 Concluded

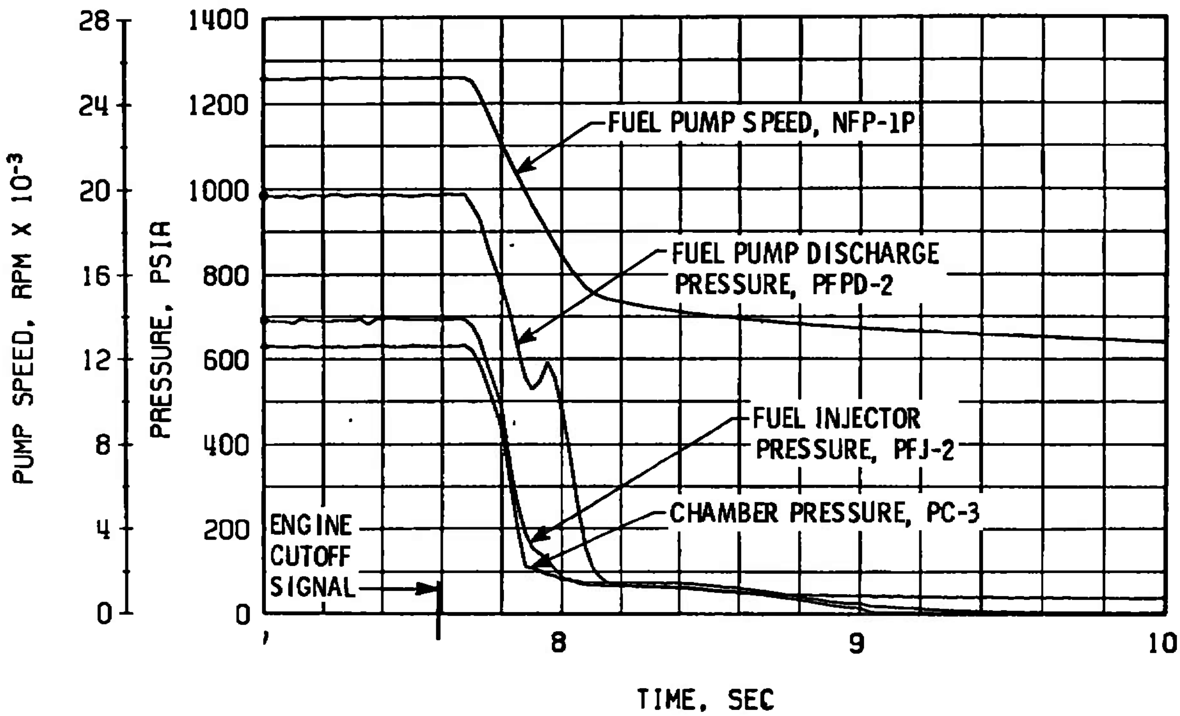


a. Thrust Chamber Fuel System, Start

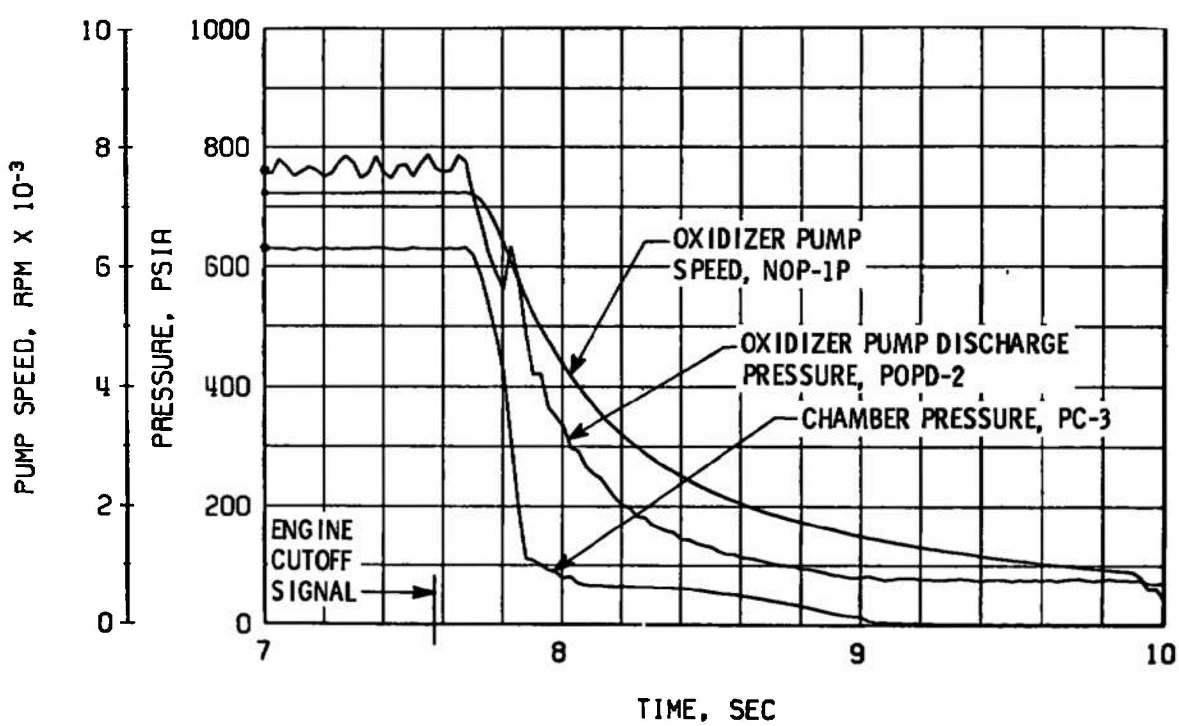


b. Thrust Chamber Oxidizer System, Start

Fig. 14 Engine Transient Operation, Firing 34B

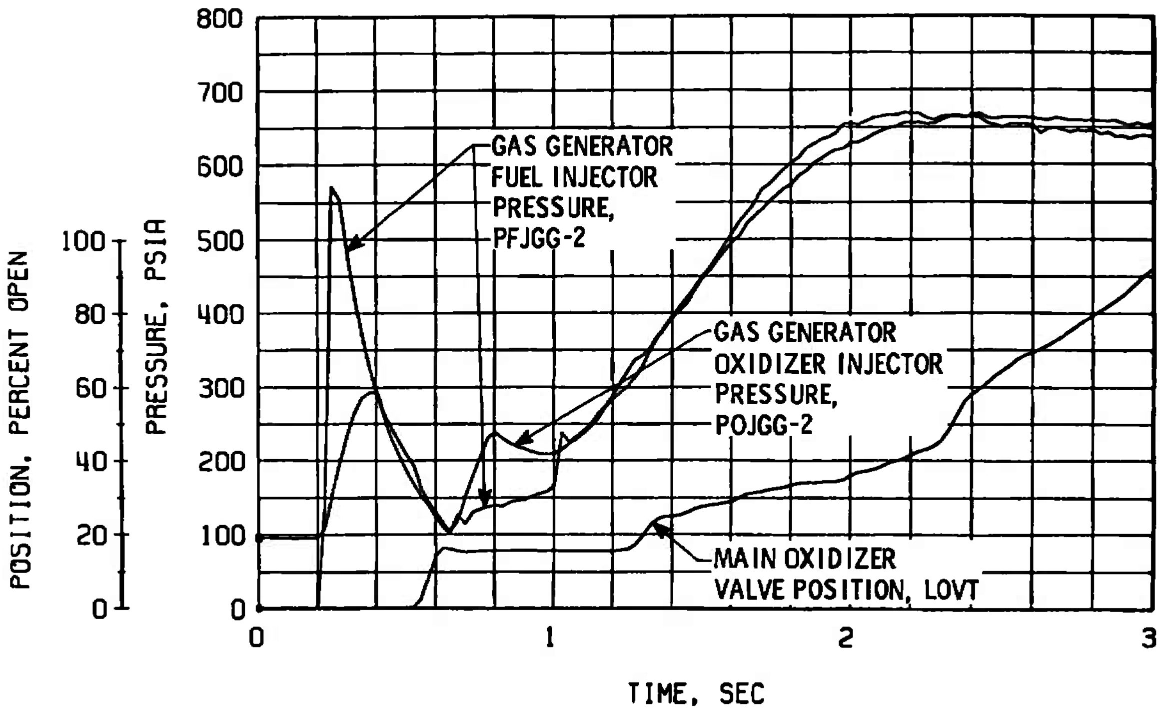


c. Thrust Chamber Fuel System, Shutdown

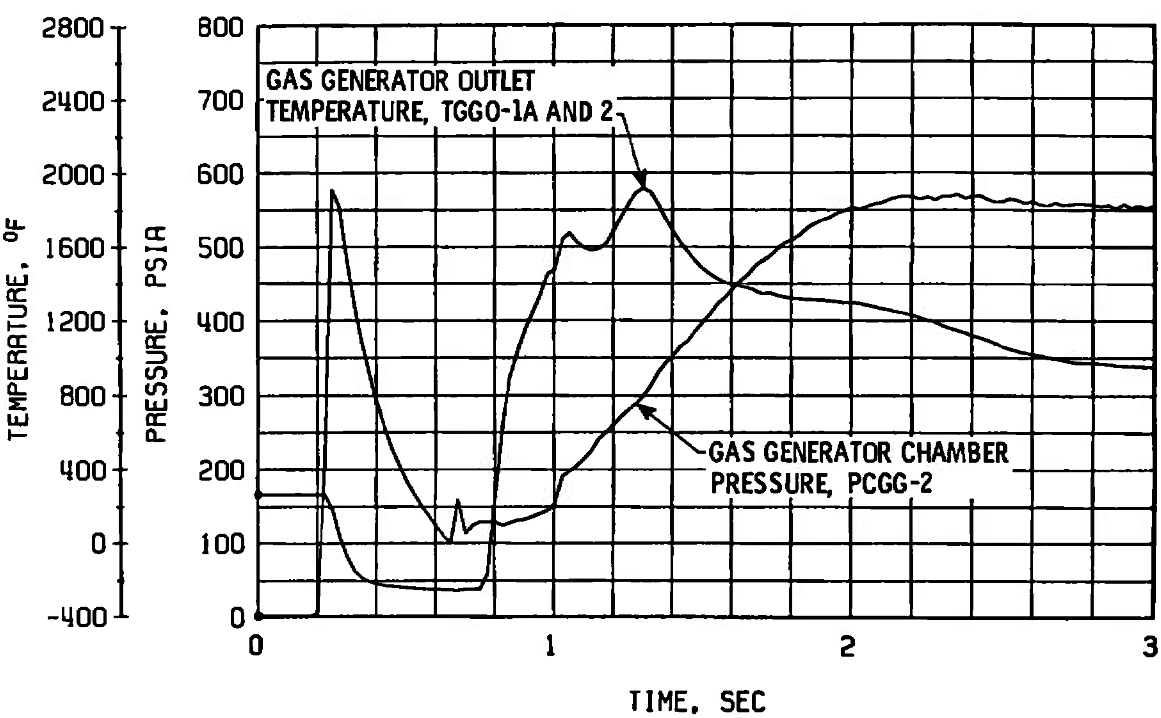


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 14 Continued

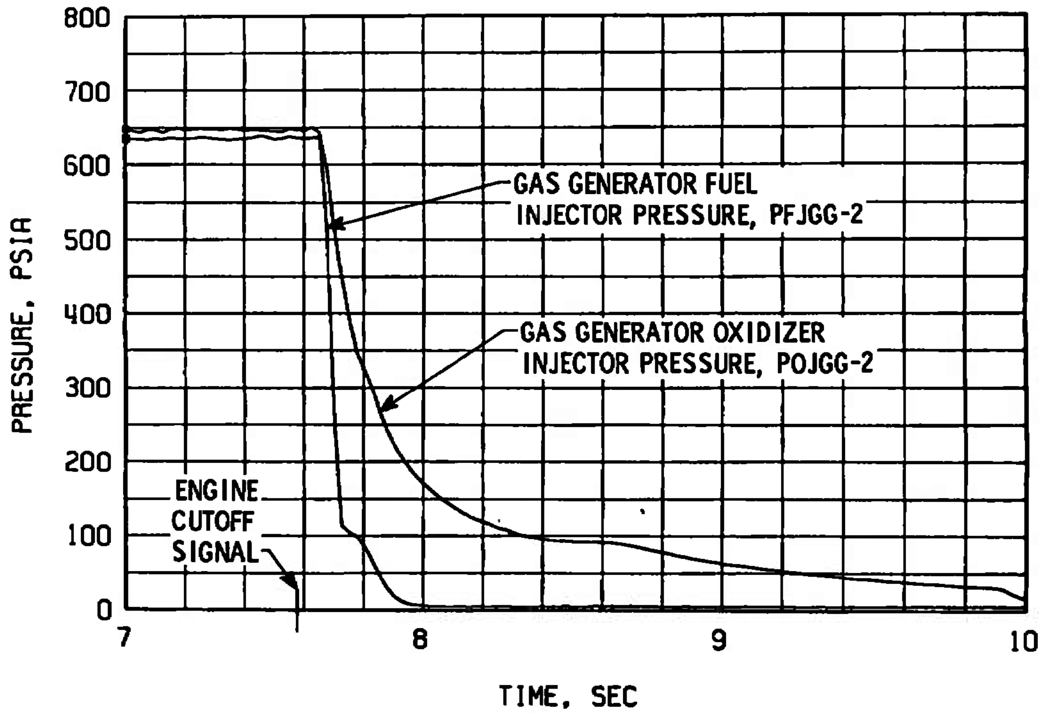


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

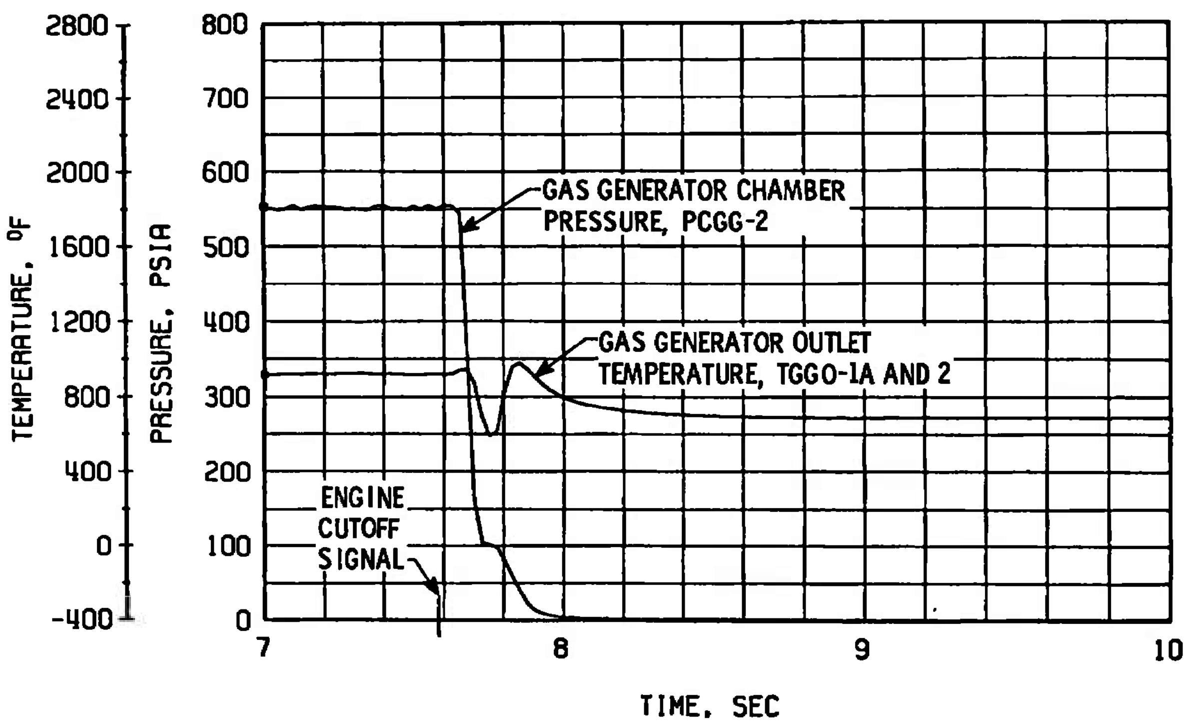


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 14 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 14 Concluded

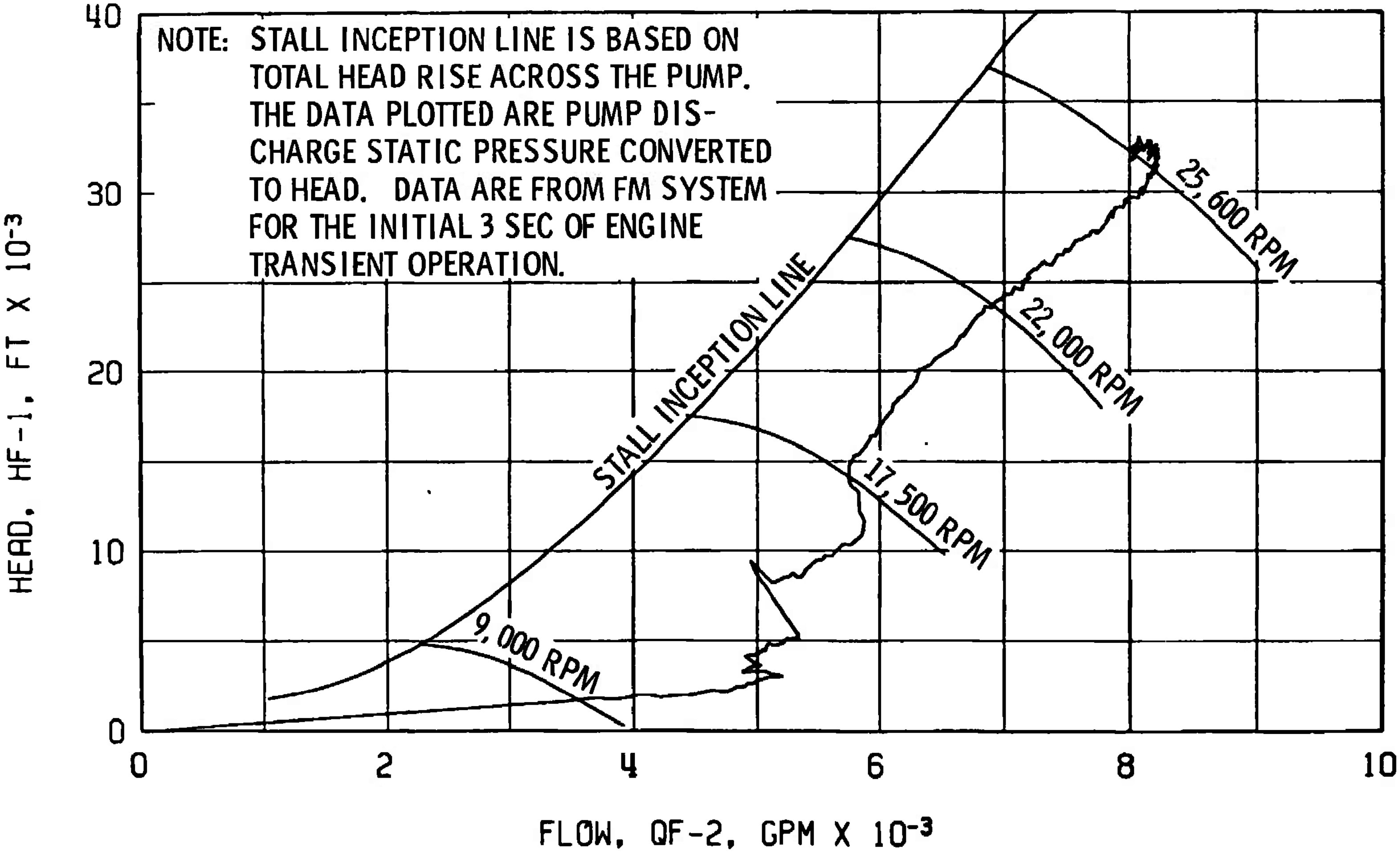


Fig. 15 Fuel Pump Start Transient Performance, Firing 34B

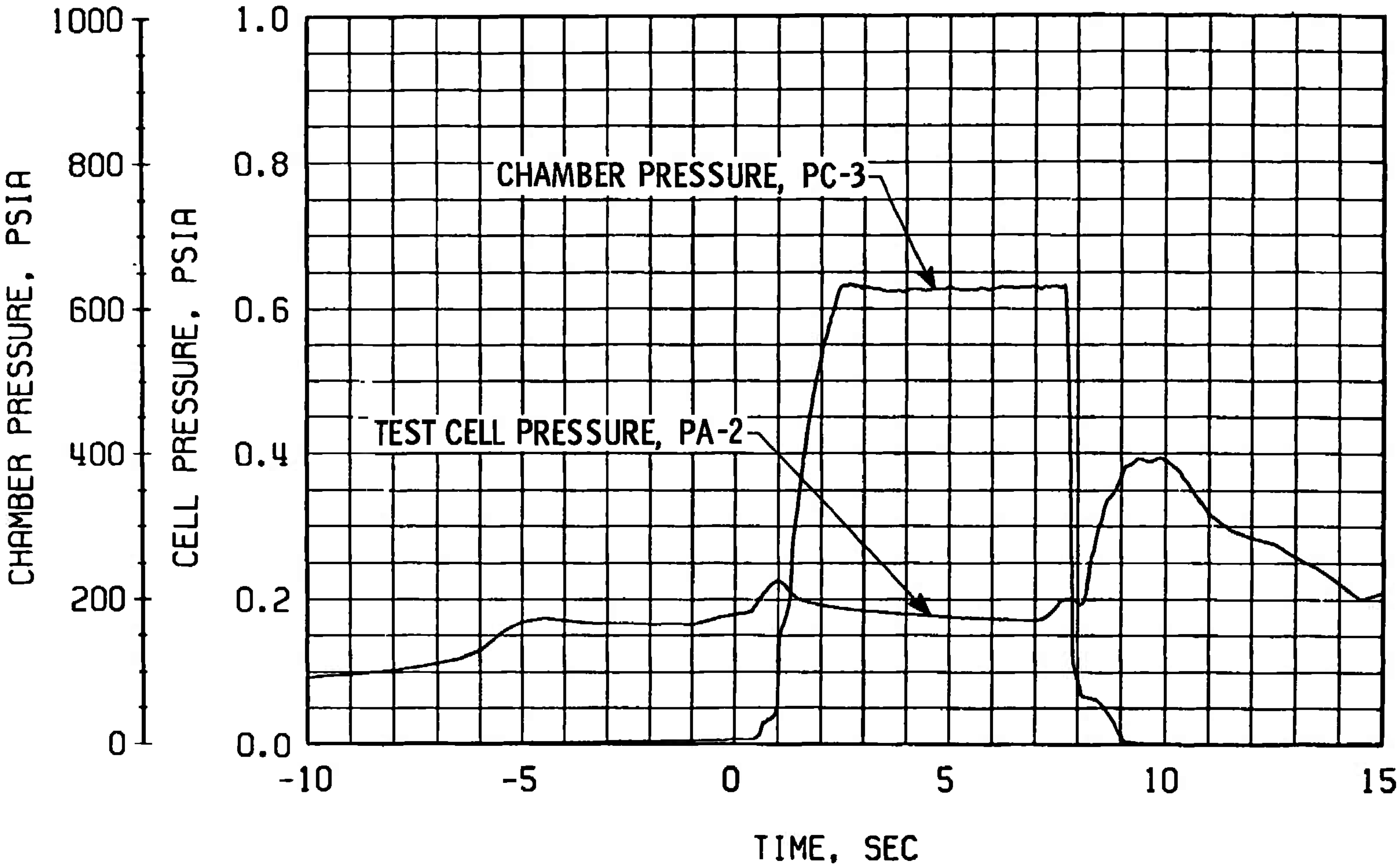
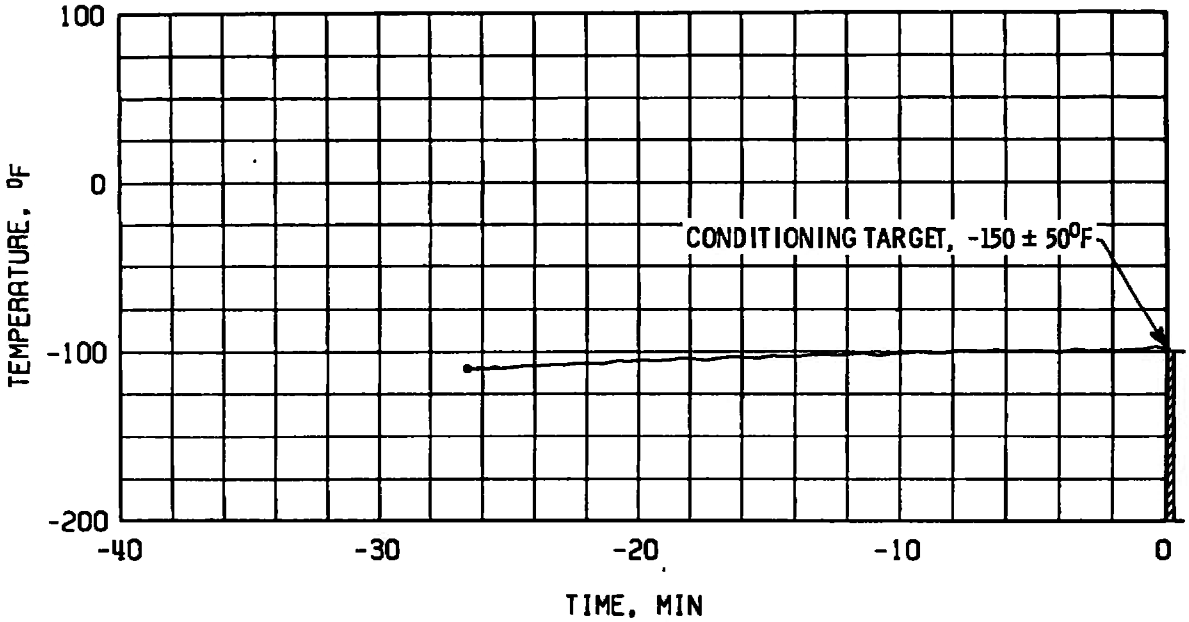
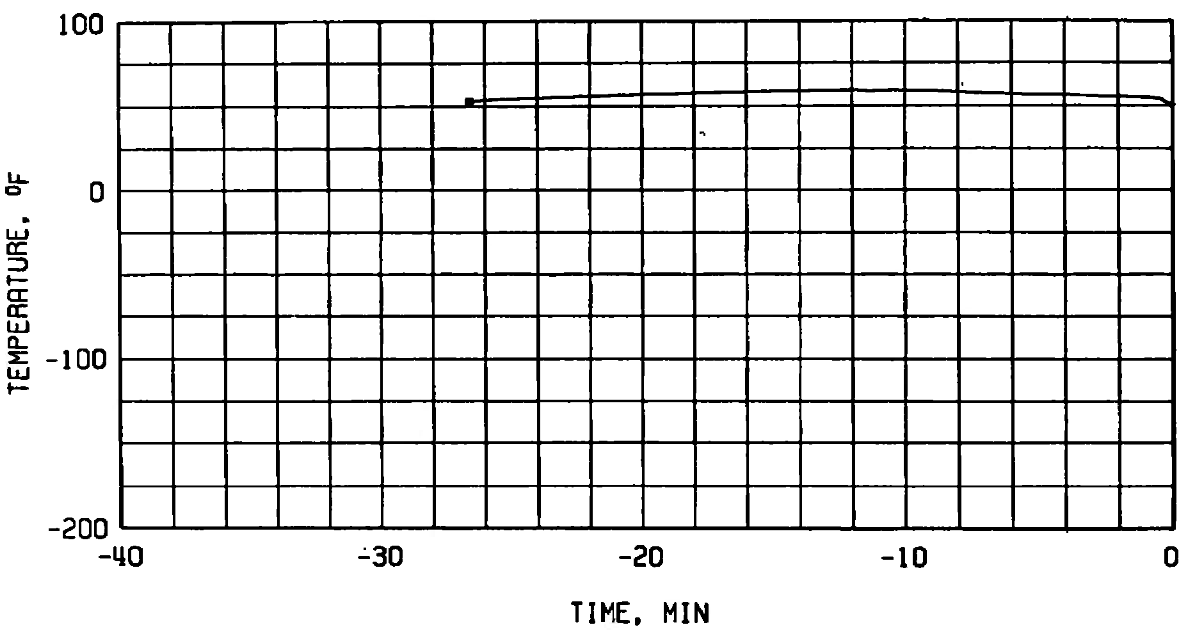


Fig. 16 Engine Ambient and Combustion Chamber Pressure, Firing 34B

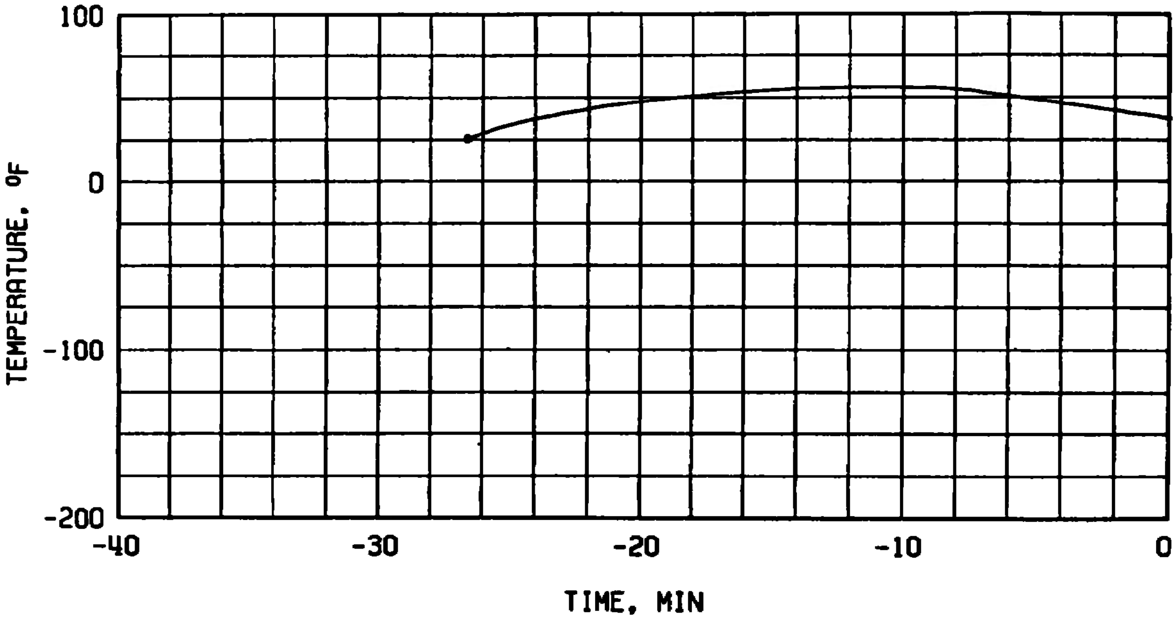


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

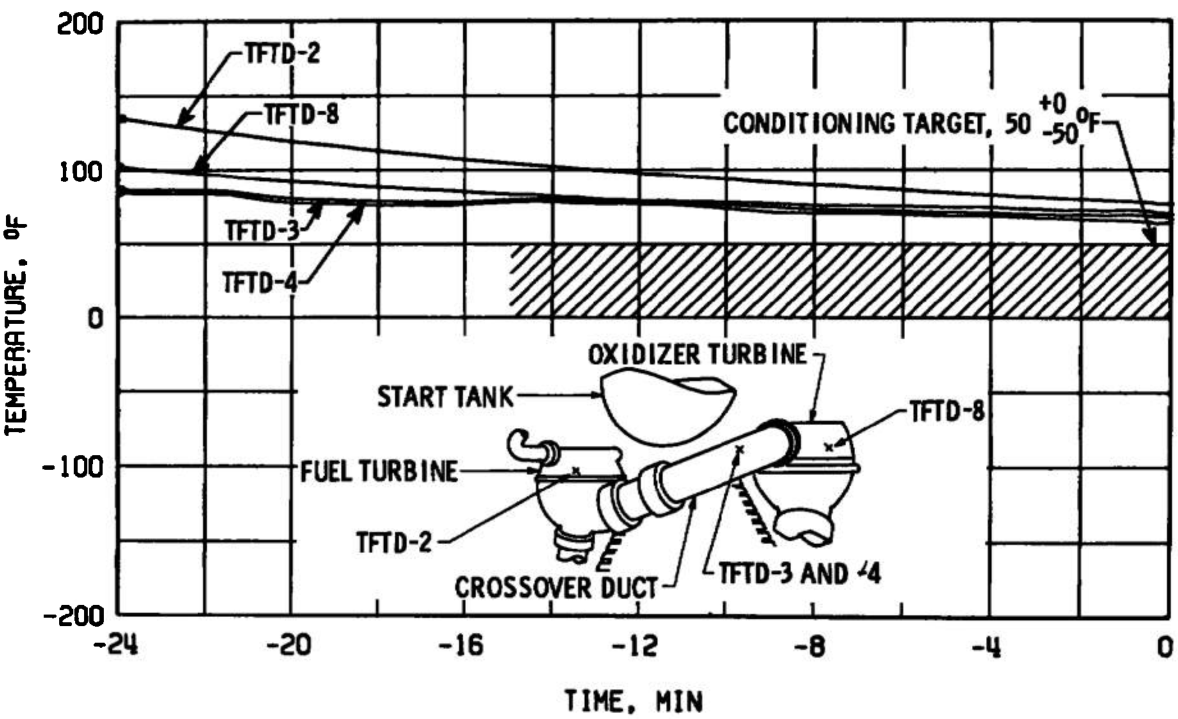


b. Gas Generator Body Temperature, TGGVRS

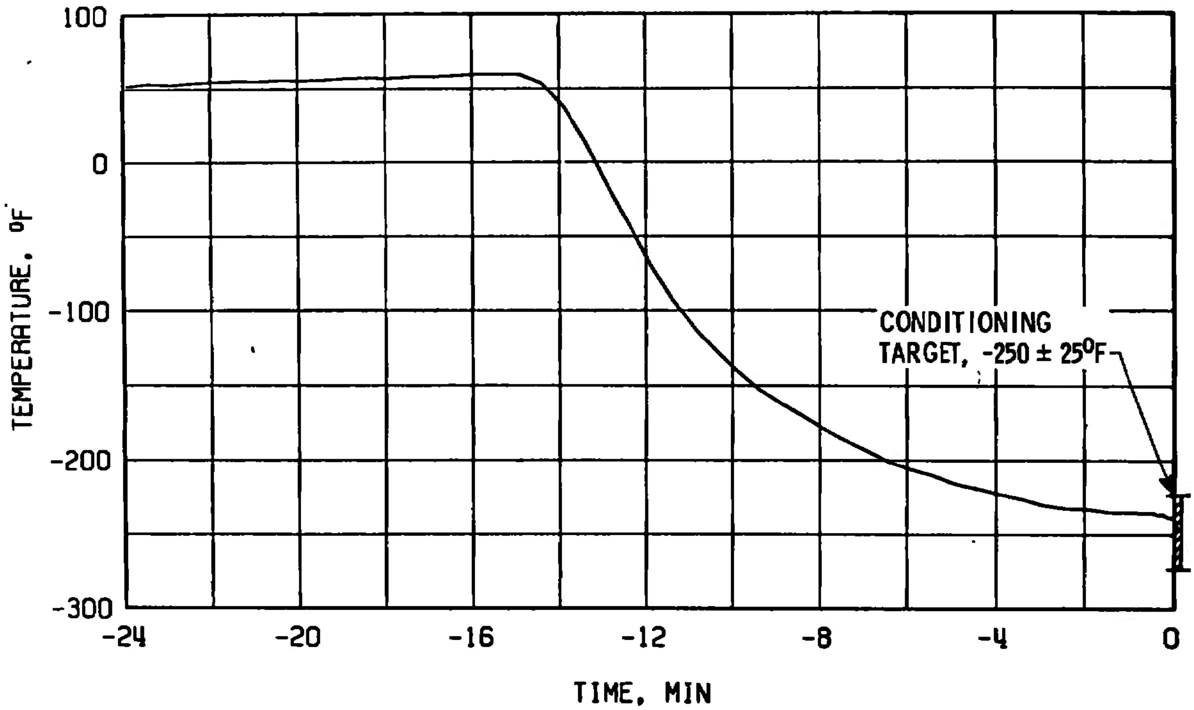
Fig. 17 Thermal Conditioning History of Engine Components, Firing 34C



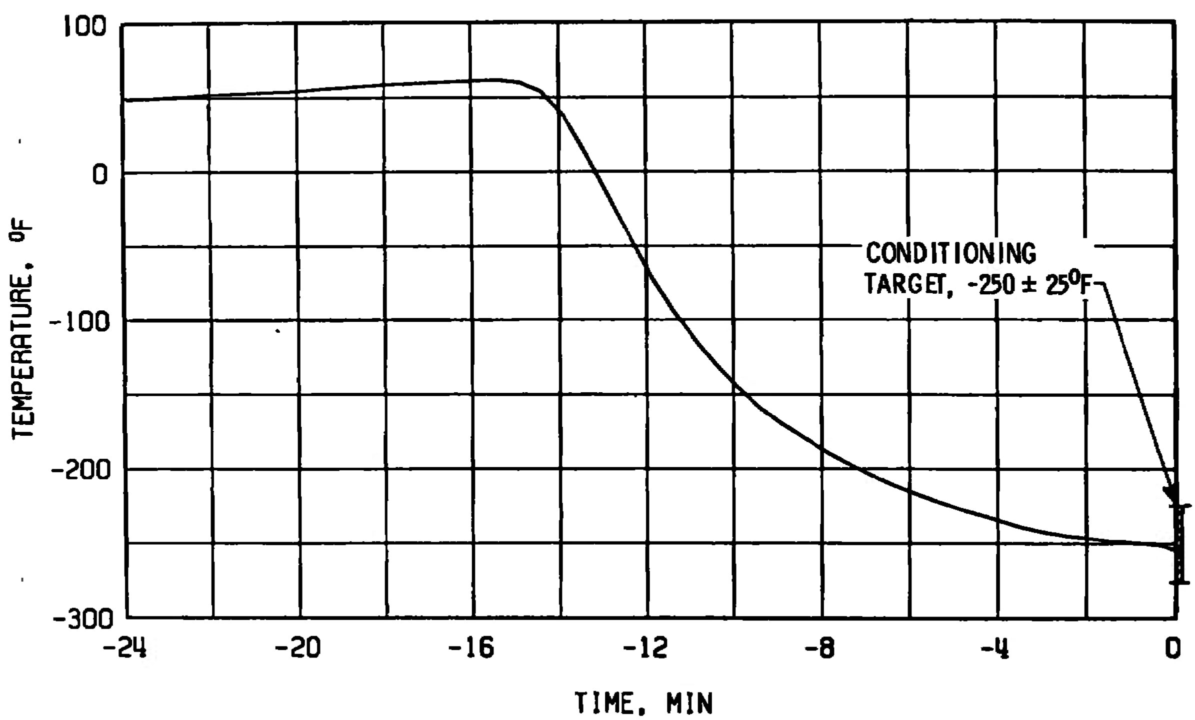
c. Start Tank Discharge Valve Opening Control, TSTDVOC



d. Crossover Duct, TFTD
Fig. 17 Continued

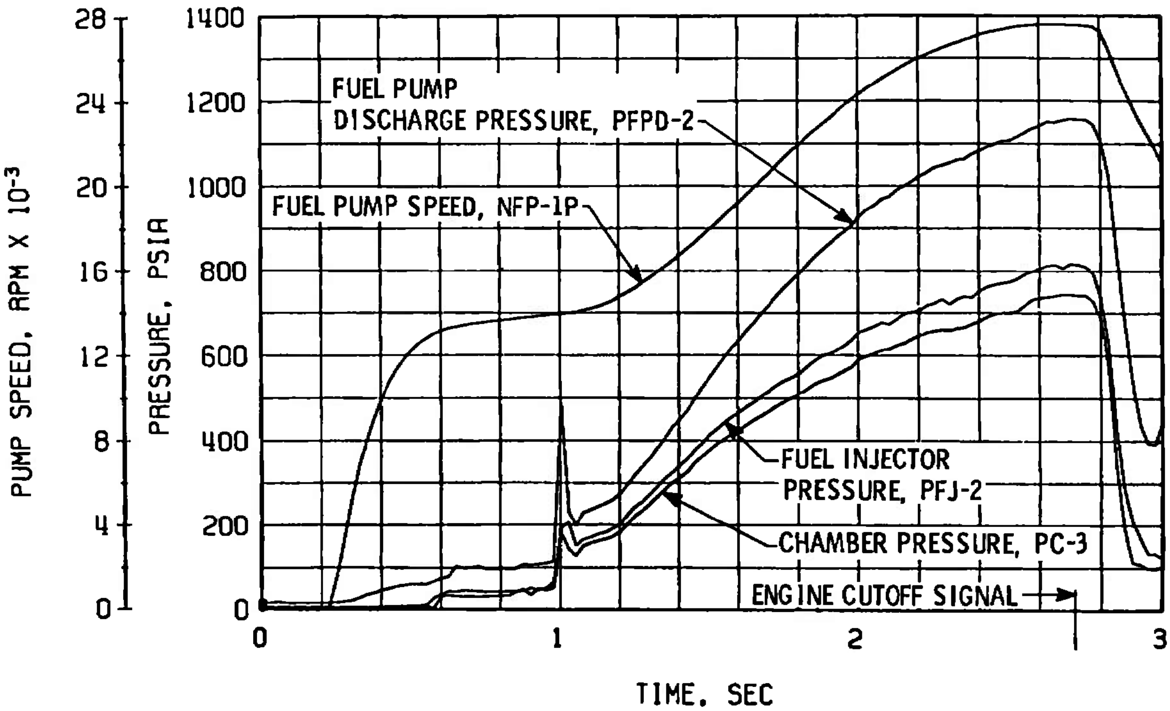


e. Thrust Chamber Throat, TTC-1P

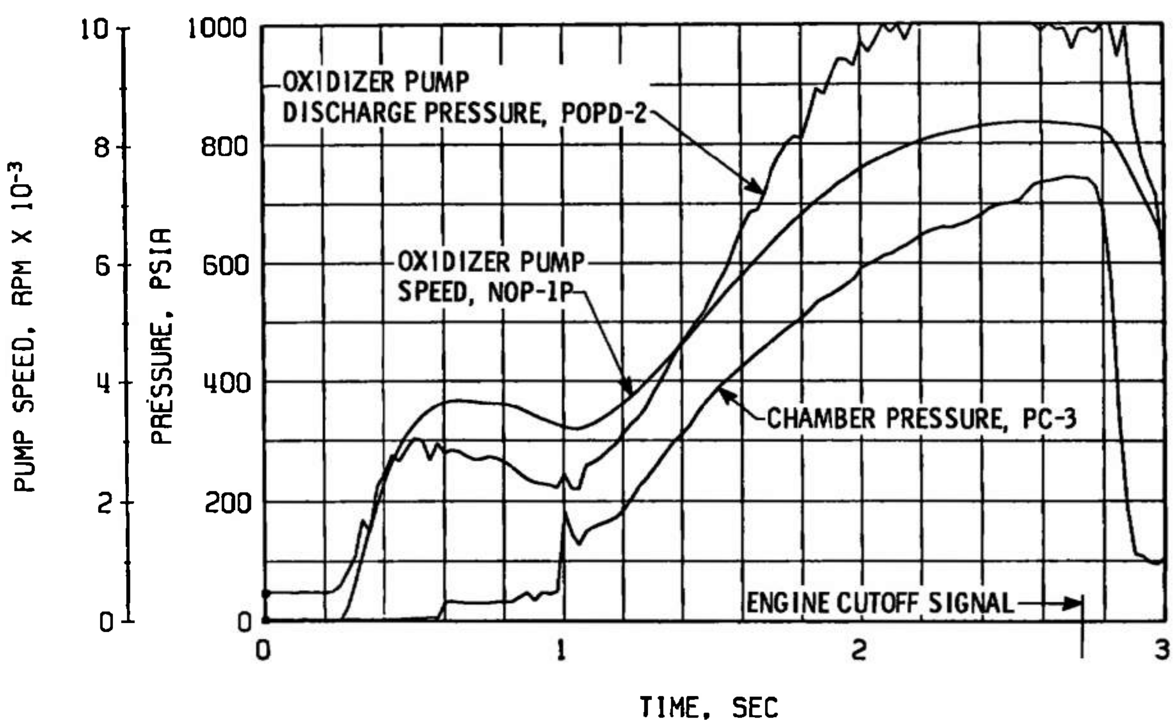


f. Thrust Chamber Throat, TTC-2

Fig. 17 Concluded

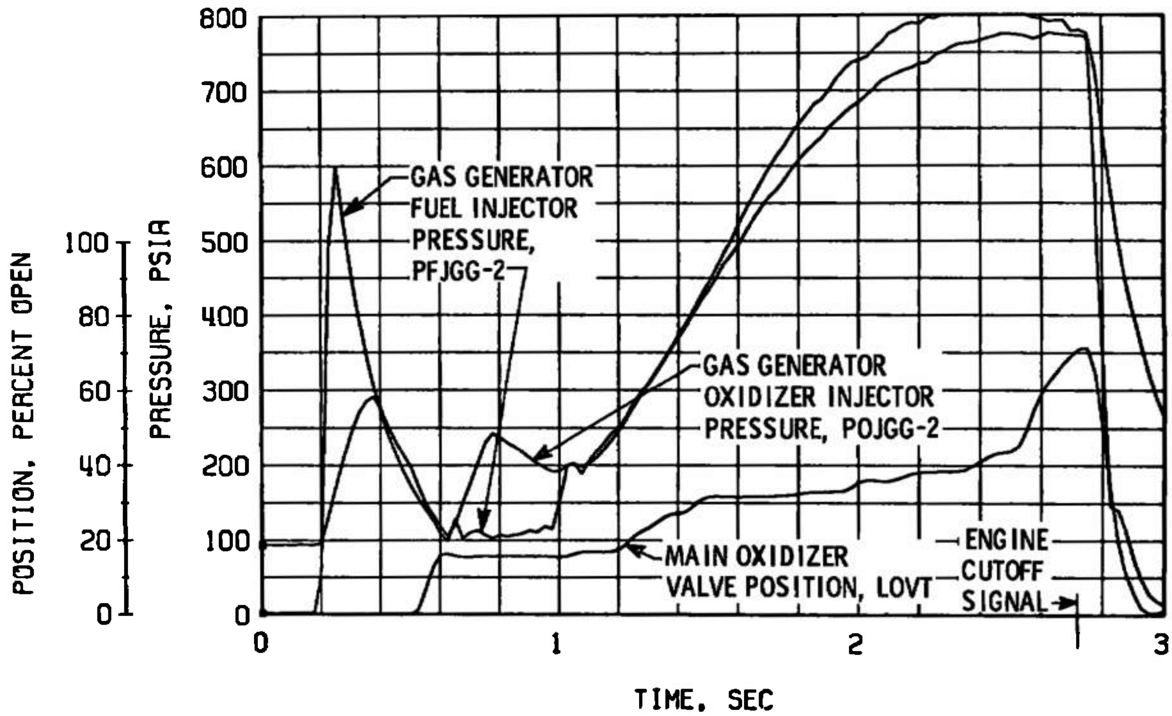


a. Thrust Chamber Fuel System, Start and Shutdown

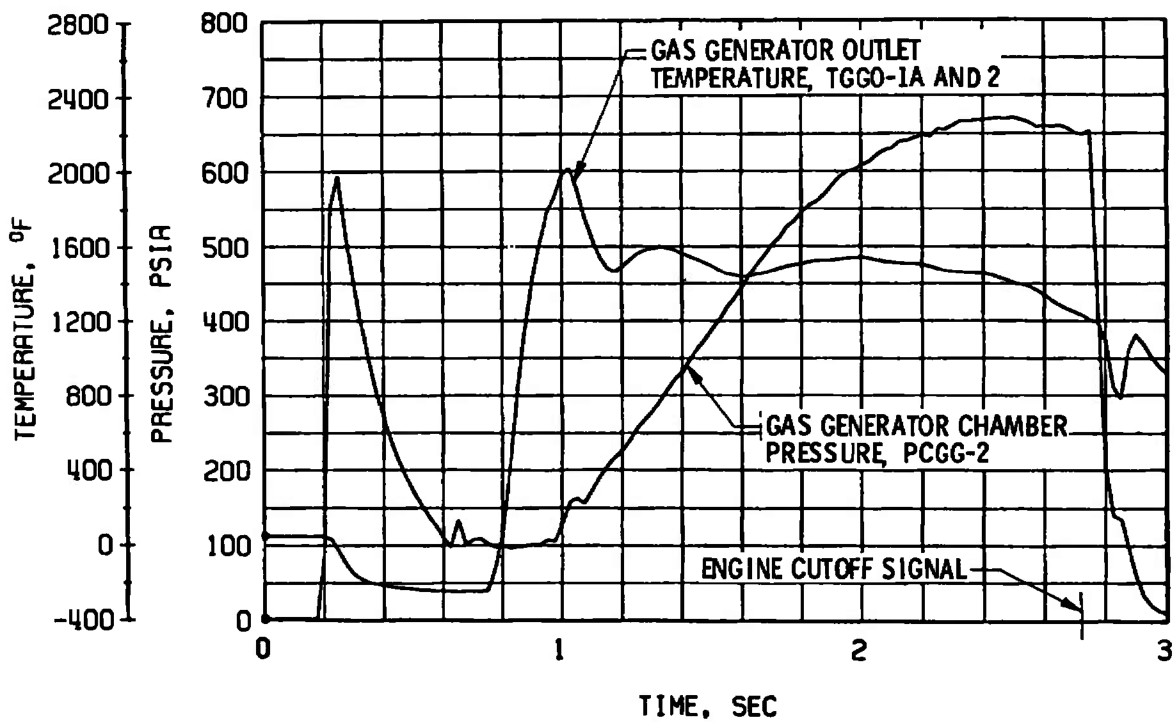


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 18 Engine Transient Operation, Firing 34C



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 18 Concluded

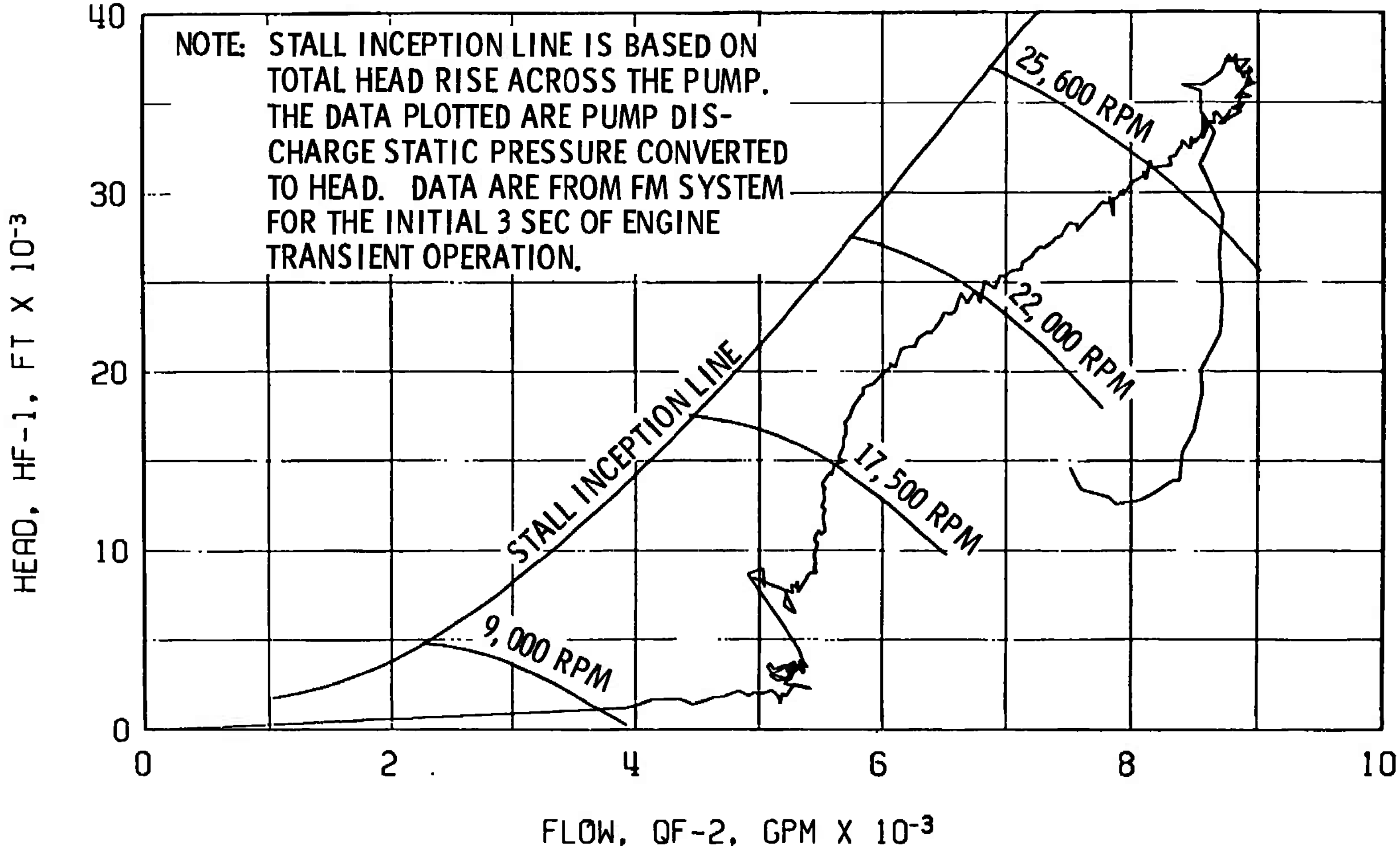


Fig. 19 Fuel Pump Start Transient Performance, Firing 34C

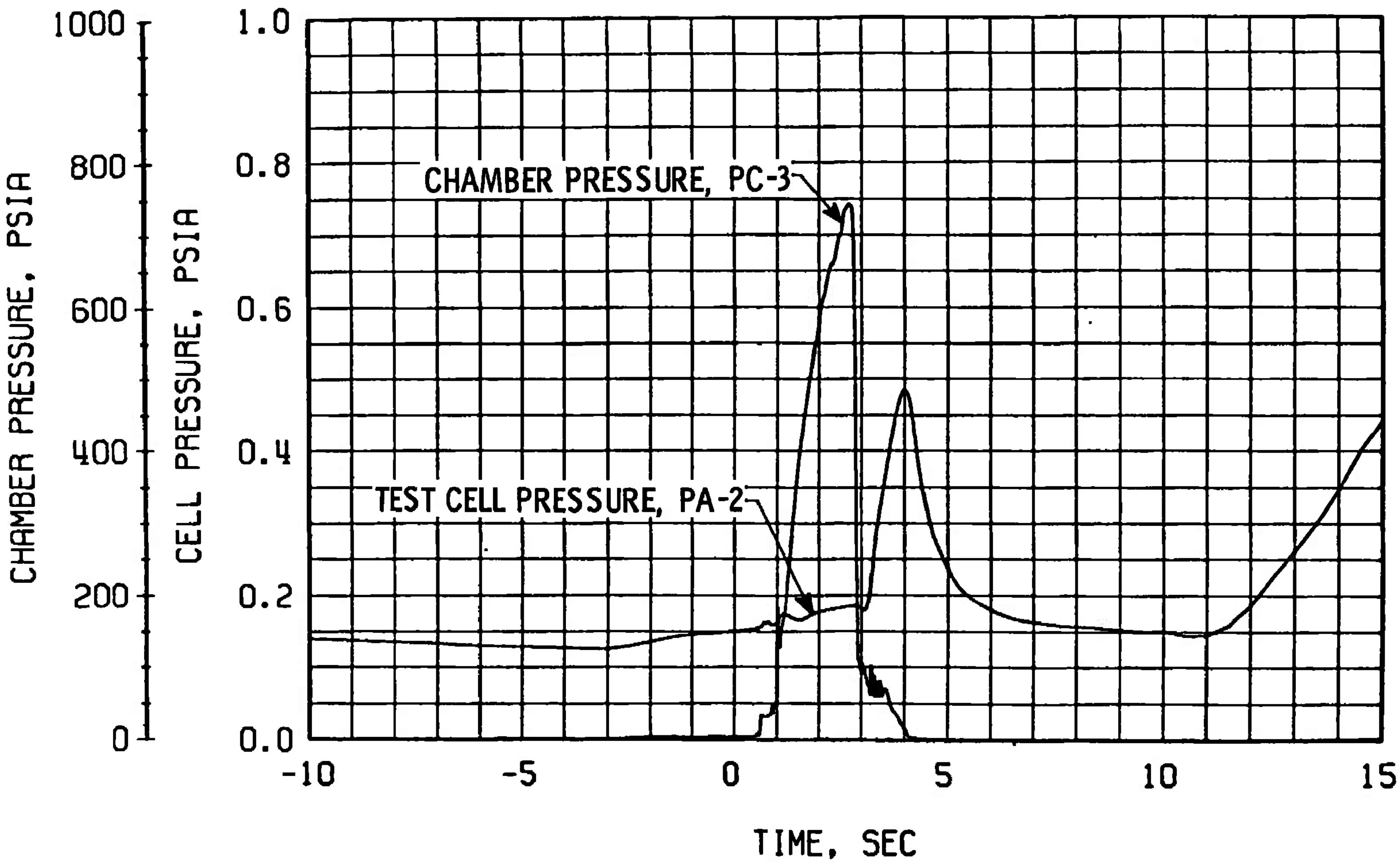
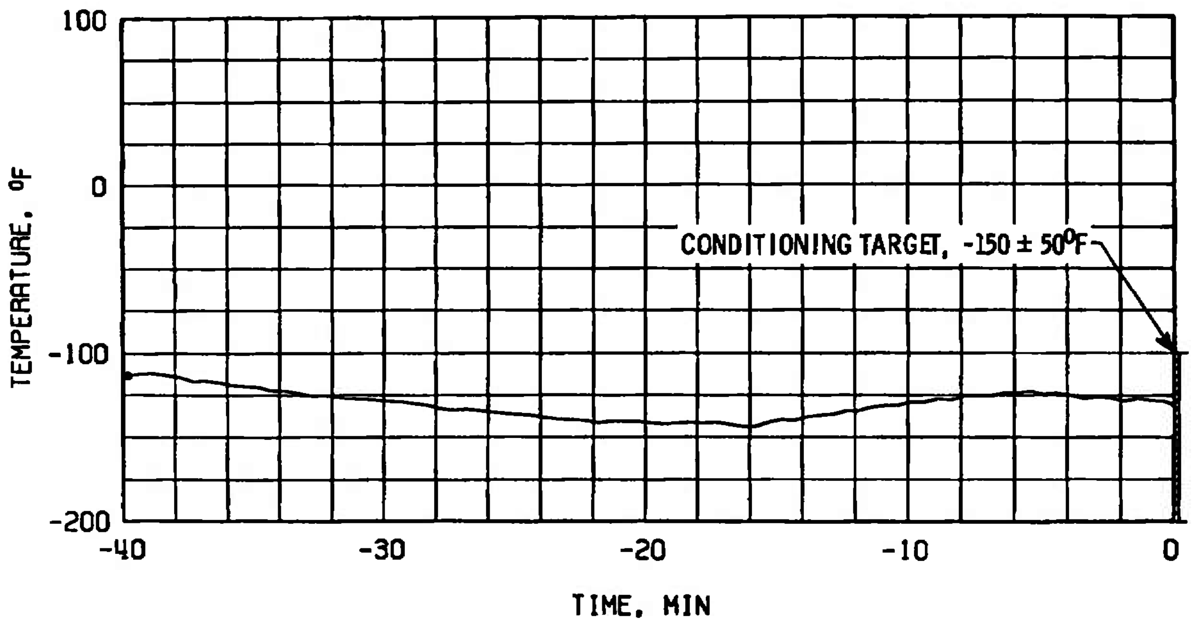
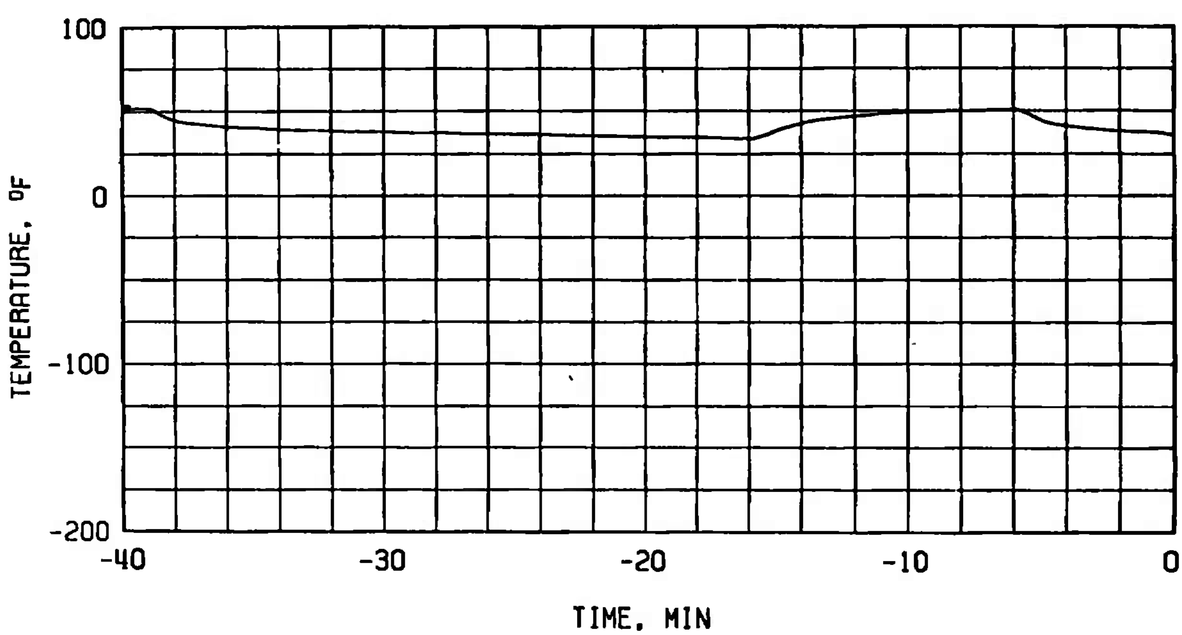


Fig. 20 Engine Ambient and Combustion Chamber Pressure, Firing 34C

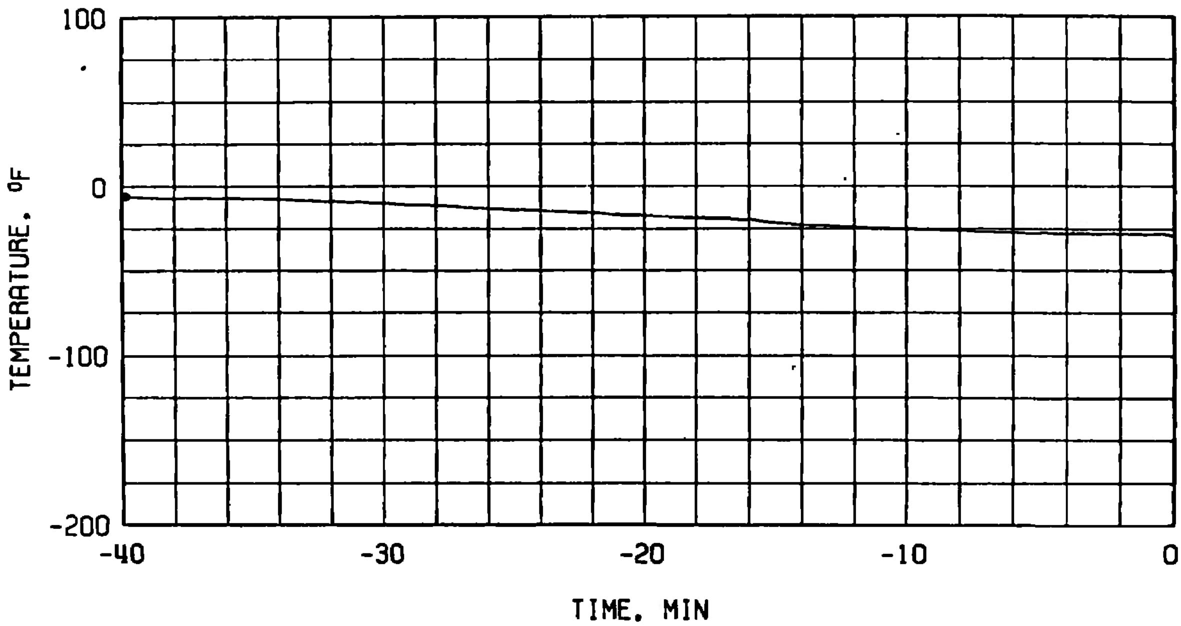


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

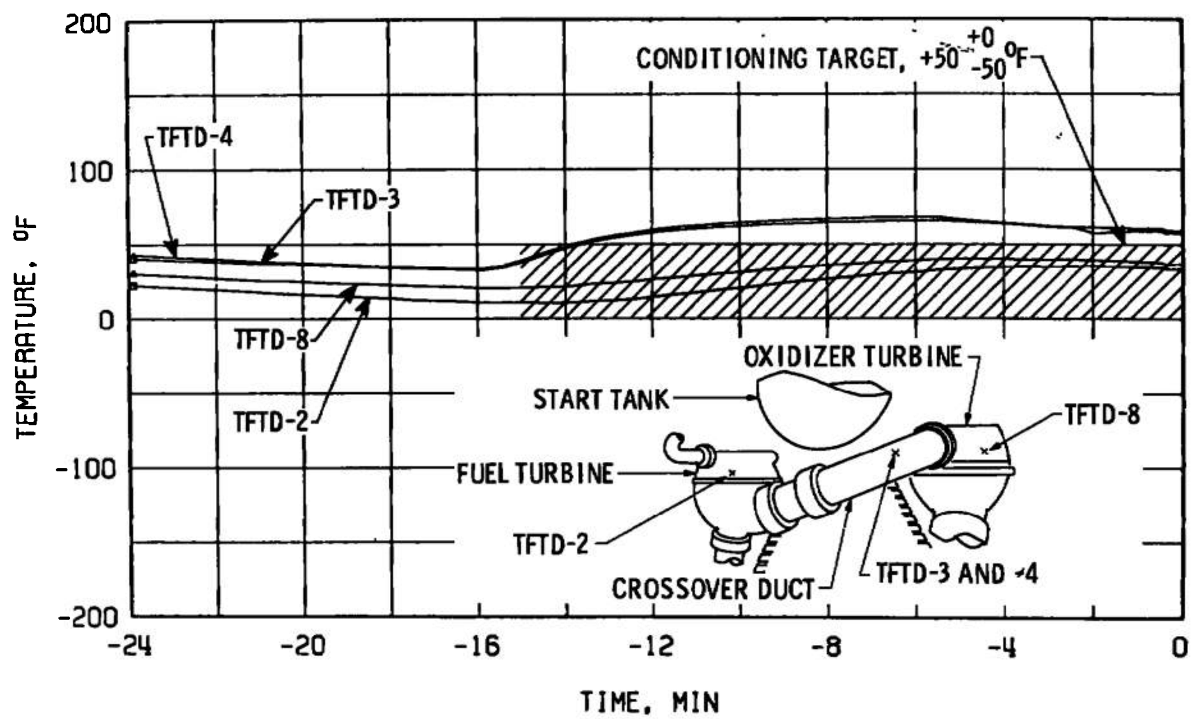


b. Gas Generator Body Temperature, TGGVRS

Fig. 21 Thermal Conditioning History of Engine Components, Firing 34D

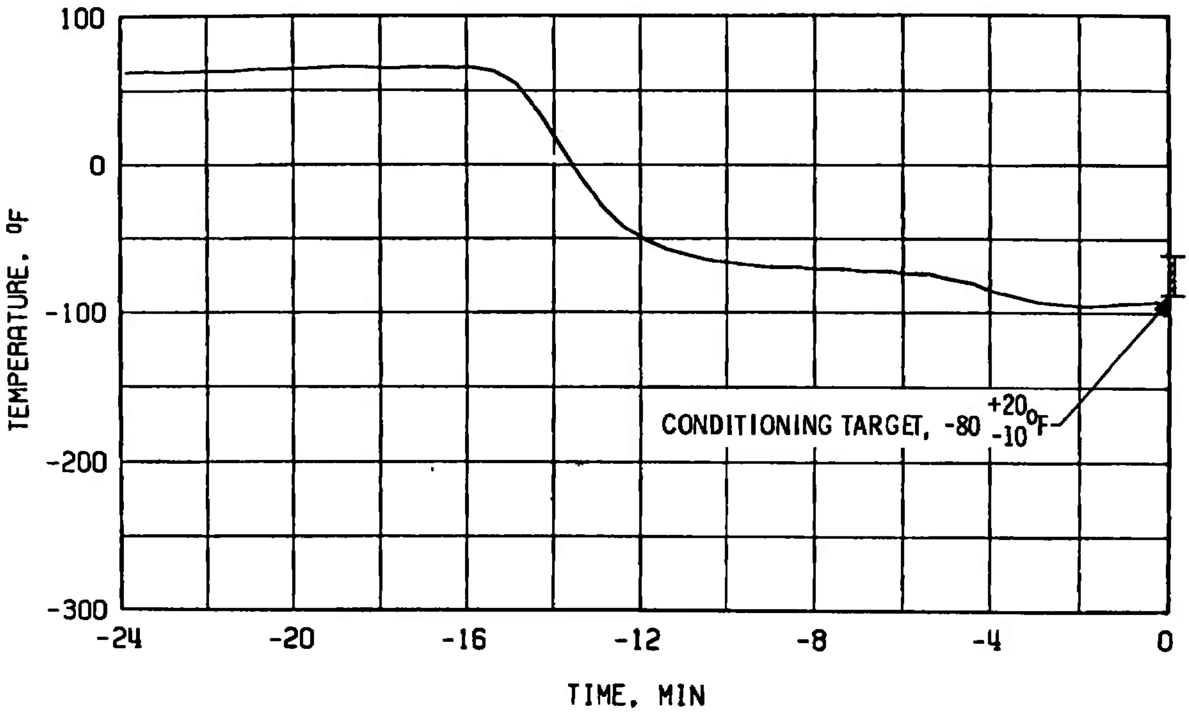


c. Start Tank Discharge Valve Opening Control, TSTDVOC

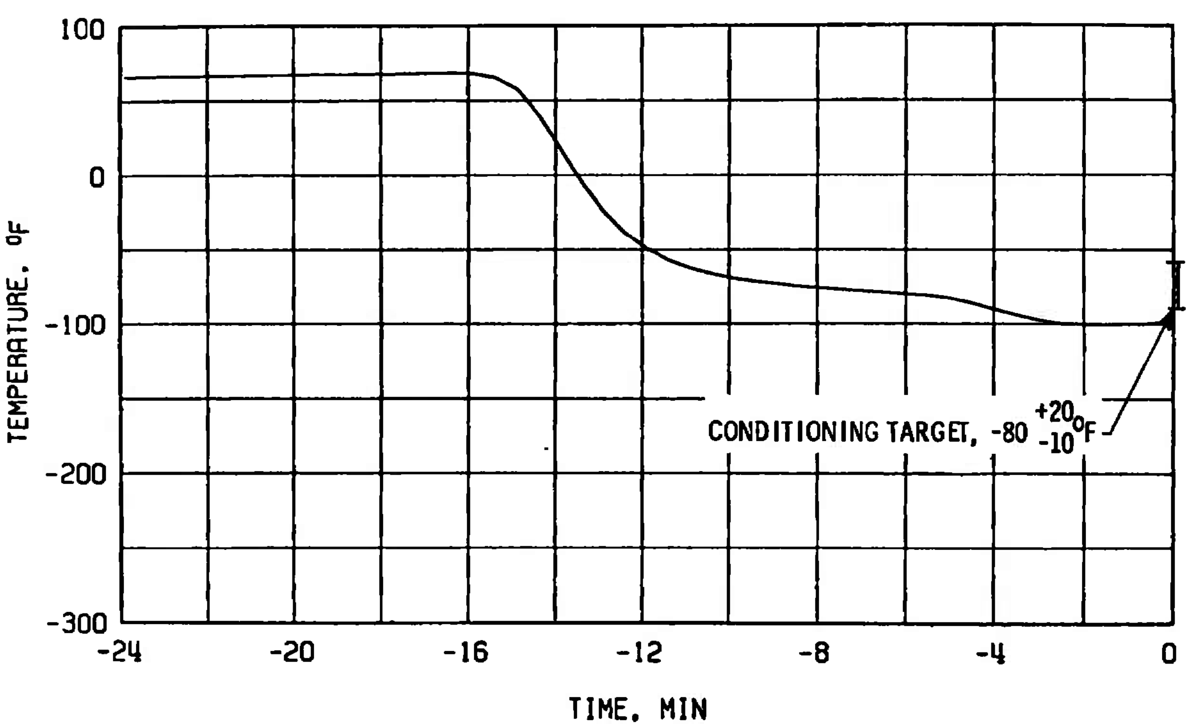


d. Crossover Duct, TFTD

Fig. 21 Continued

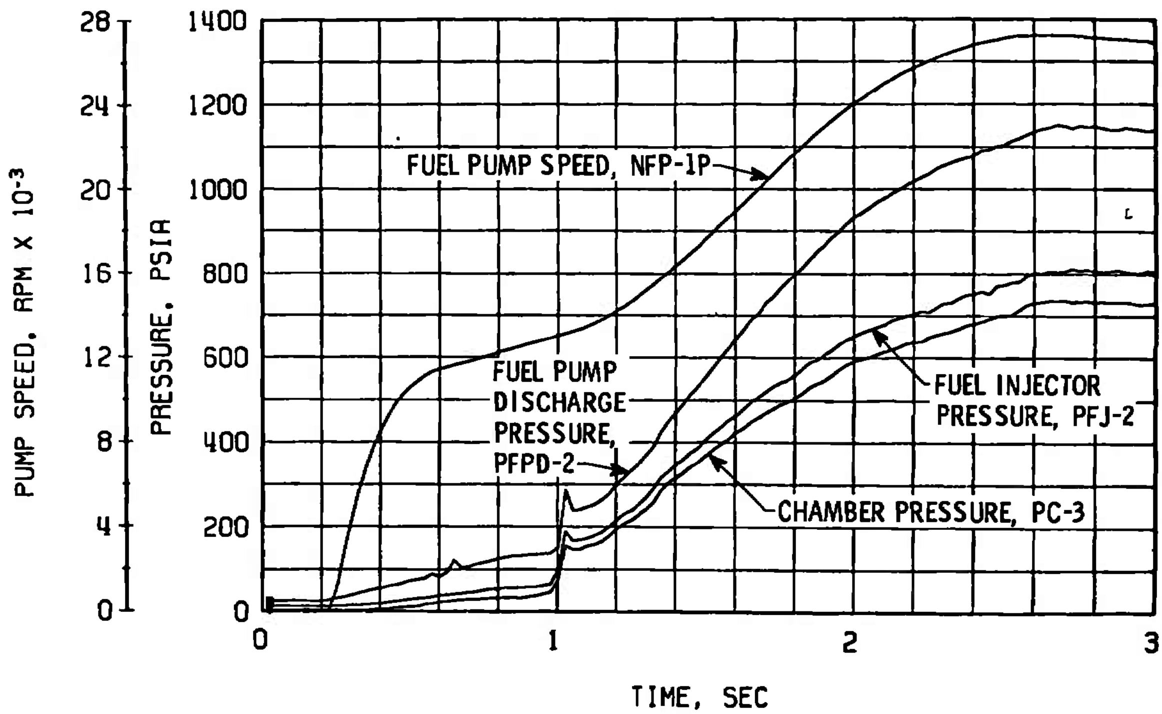


e. Thrust Chamber Throat, TTC-1P

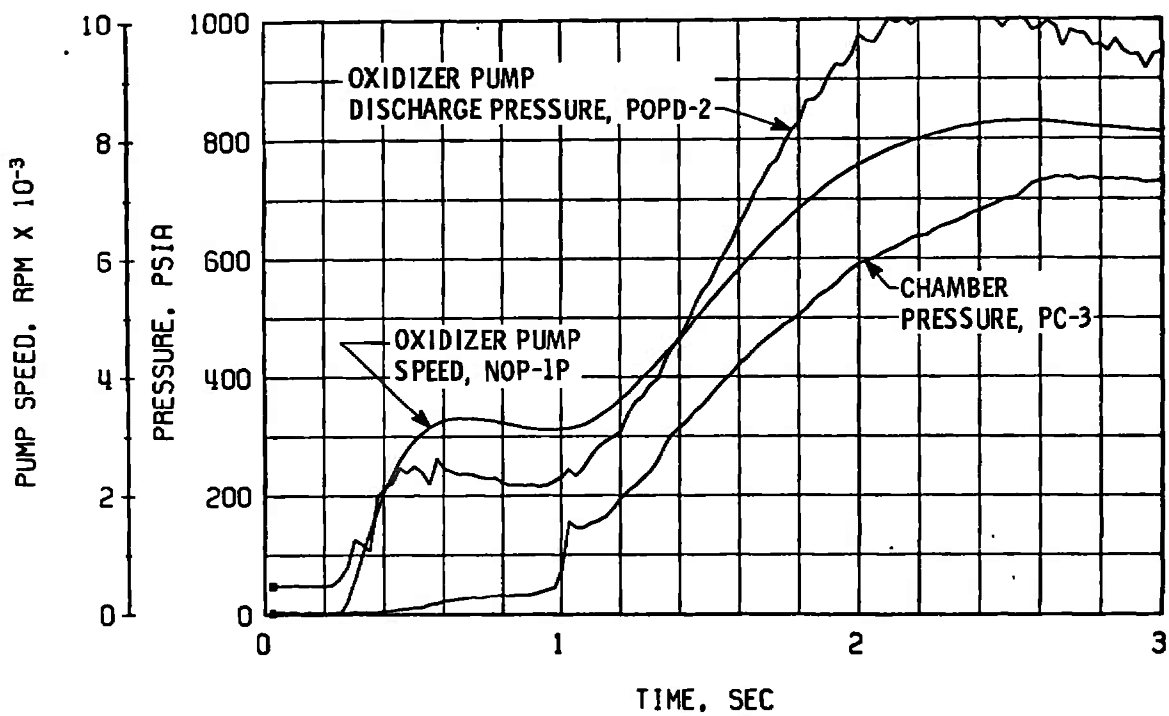


f. Thrust Chamber Throat, TTC-2

Fig. 21 Concluded

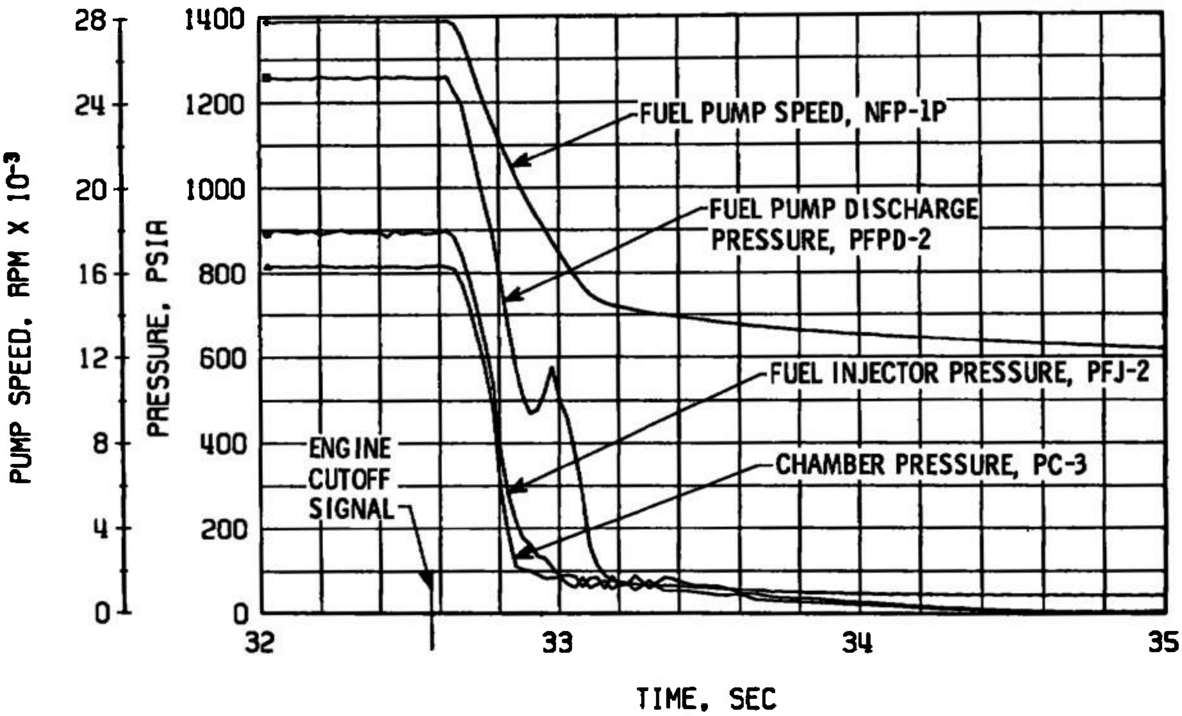


a. Thrust Chamber Fuel System, Start

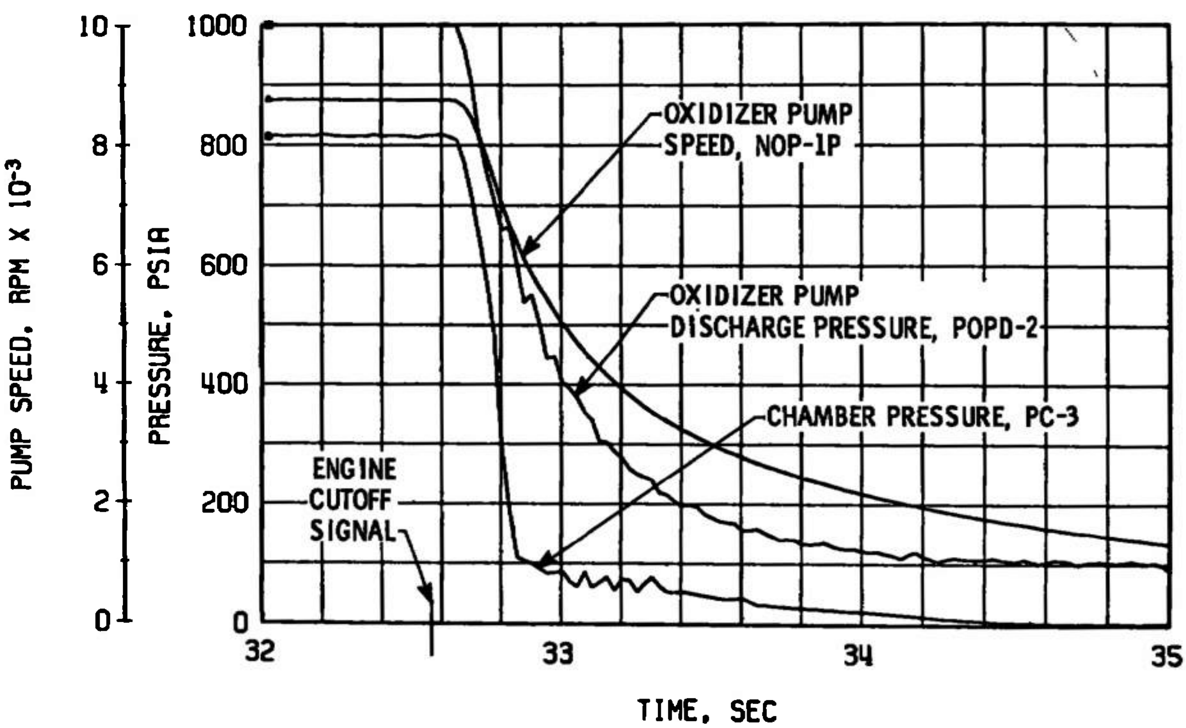


b. Thrust Chamber Oxidizer System, Start

Fig. 22 Engine Transient Operation, Firing 34D

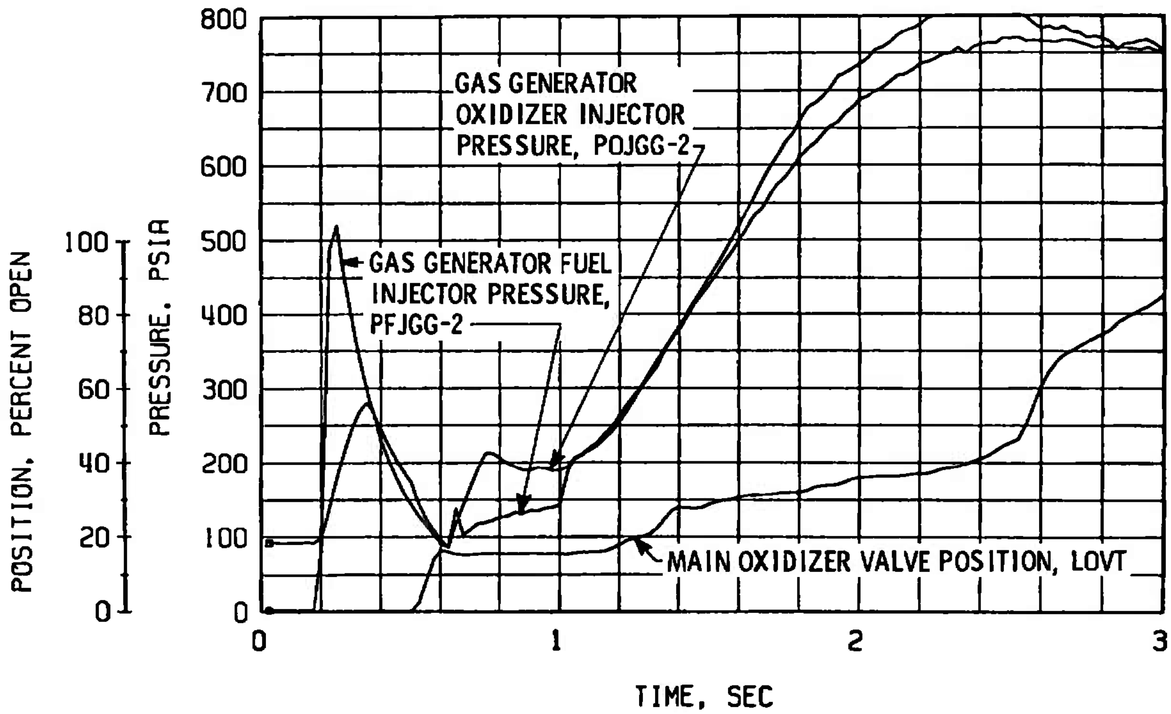


c. Thrust Chamber Fuel System, Shutdown

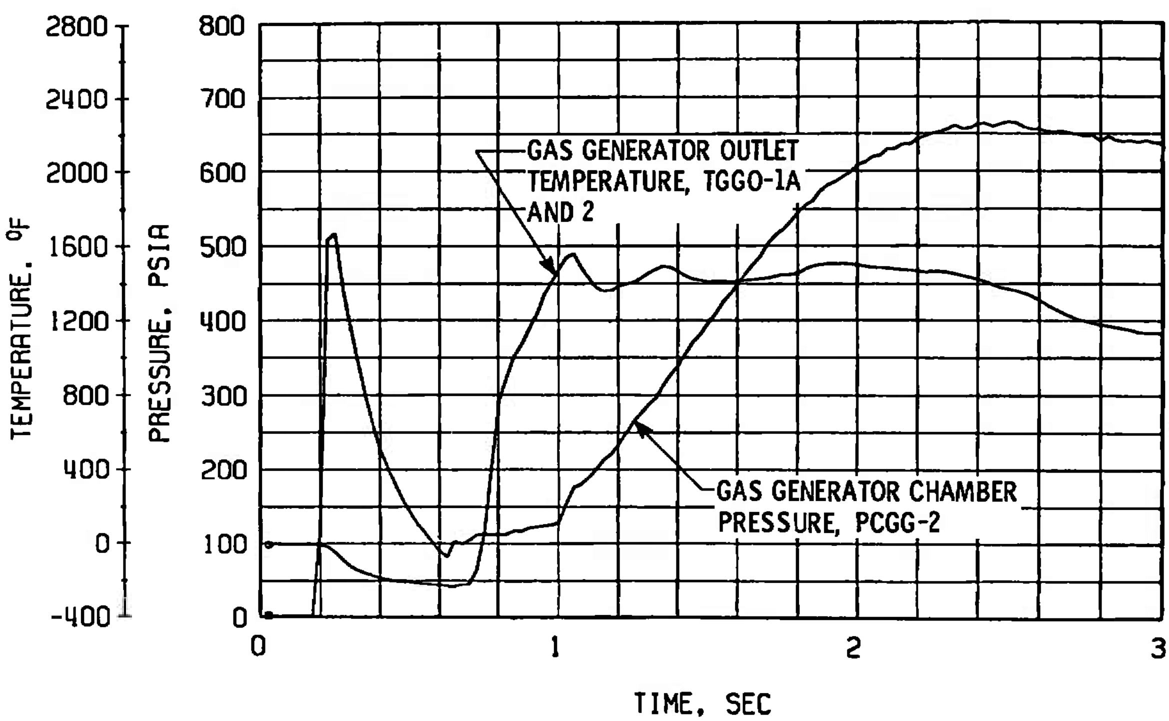


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 22 Continued

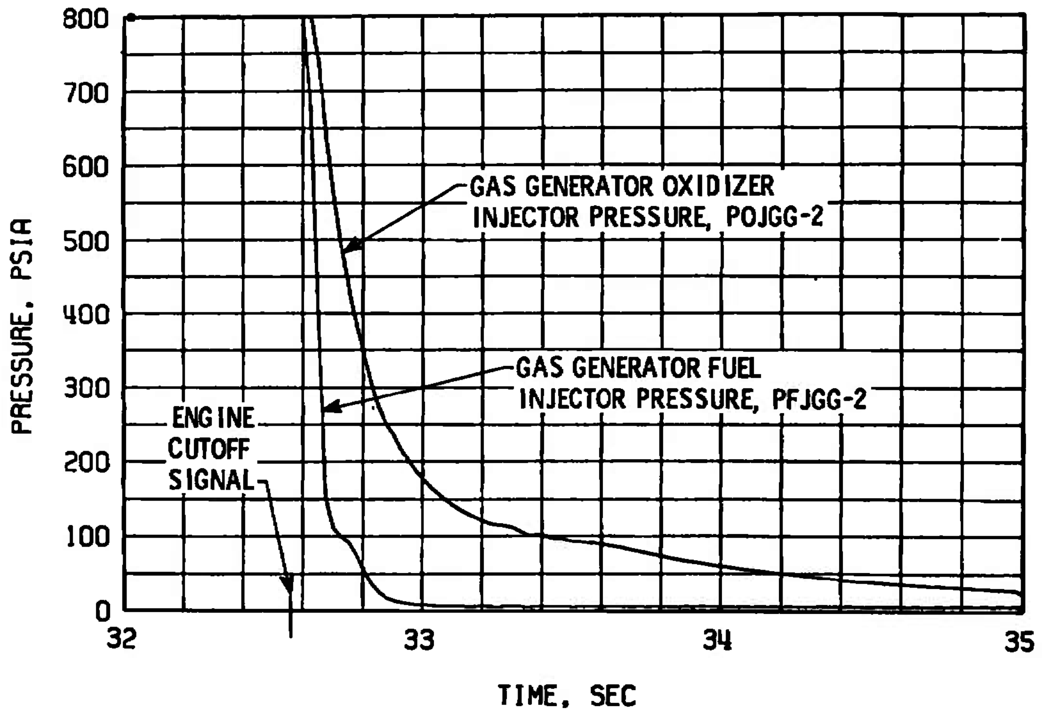


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

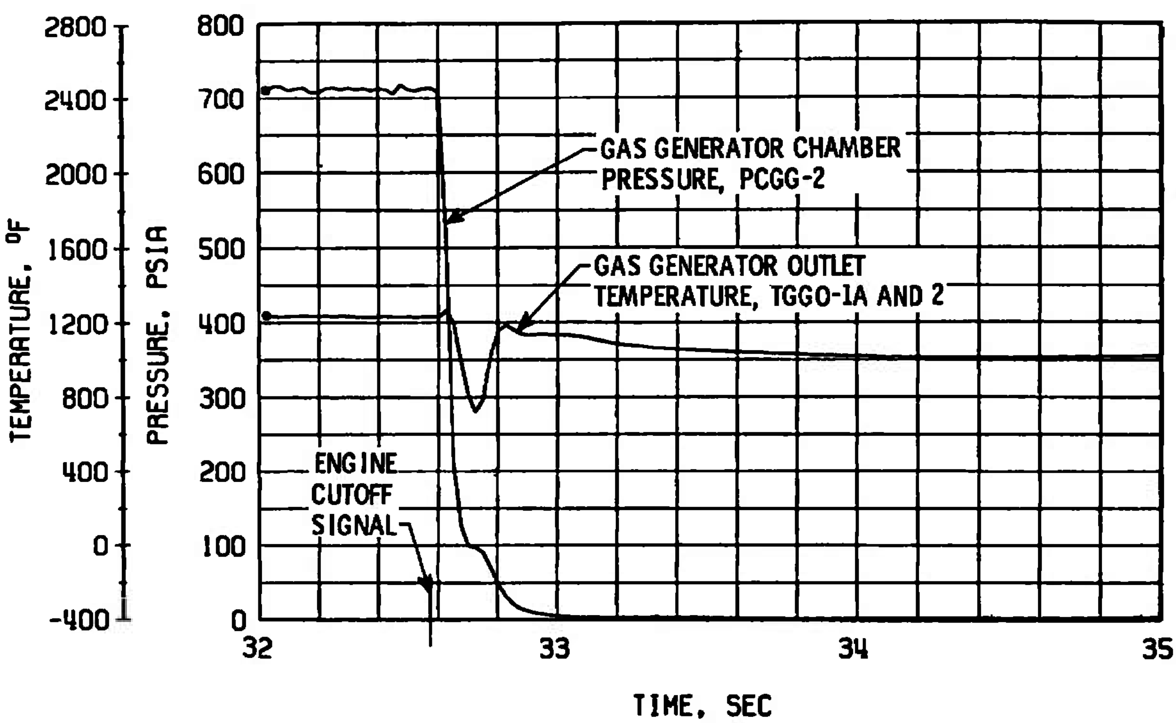


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 22 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown
Fig. 22 Concluded

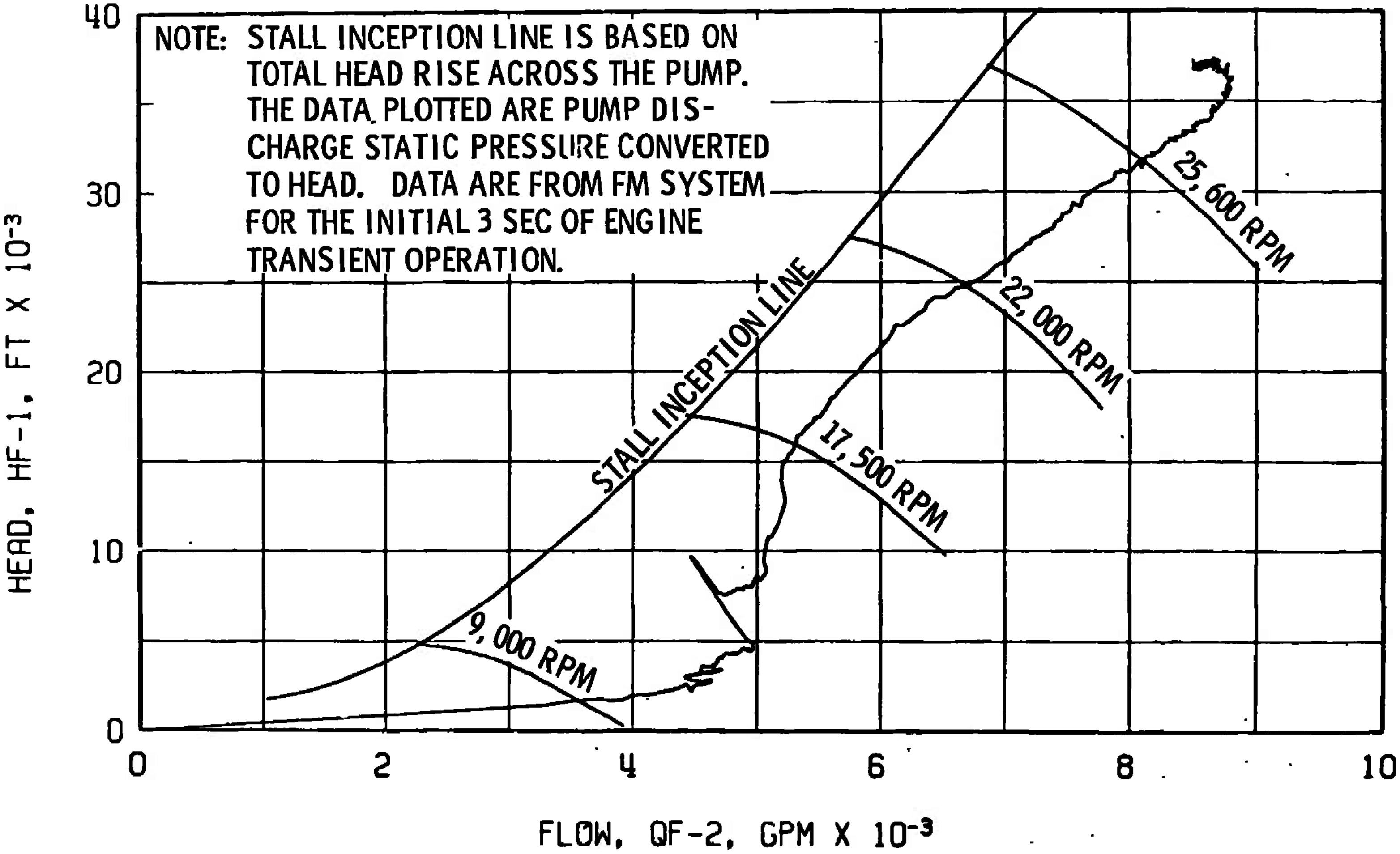


Fig. 23 Fuel Pump Start Transient Performance, Firing 34D

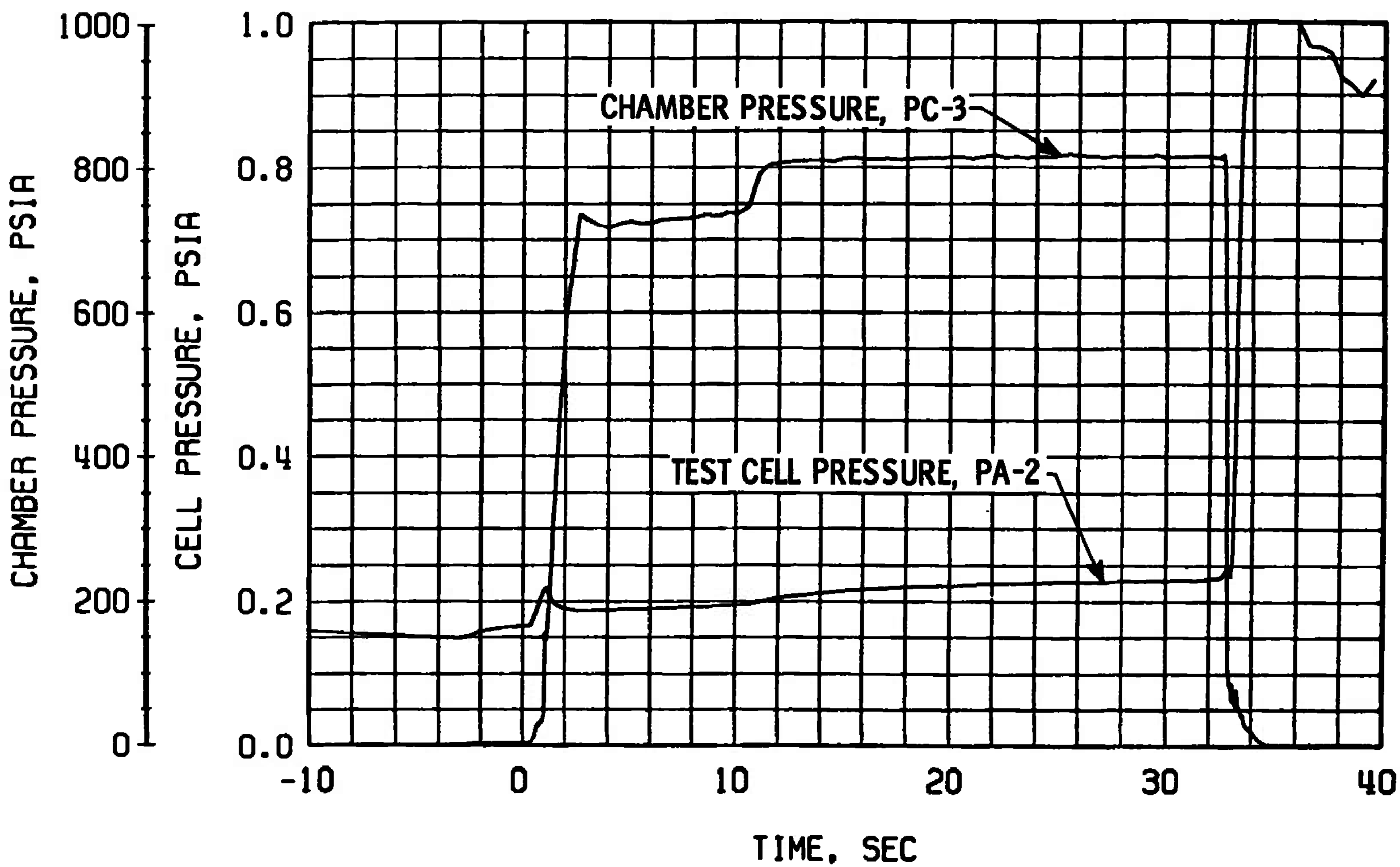
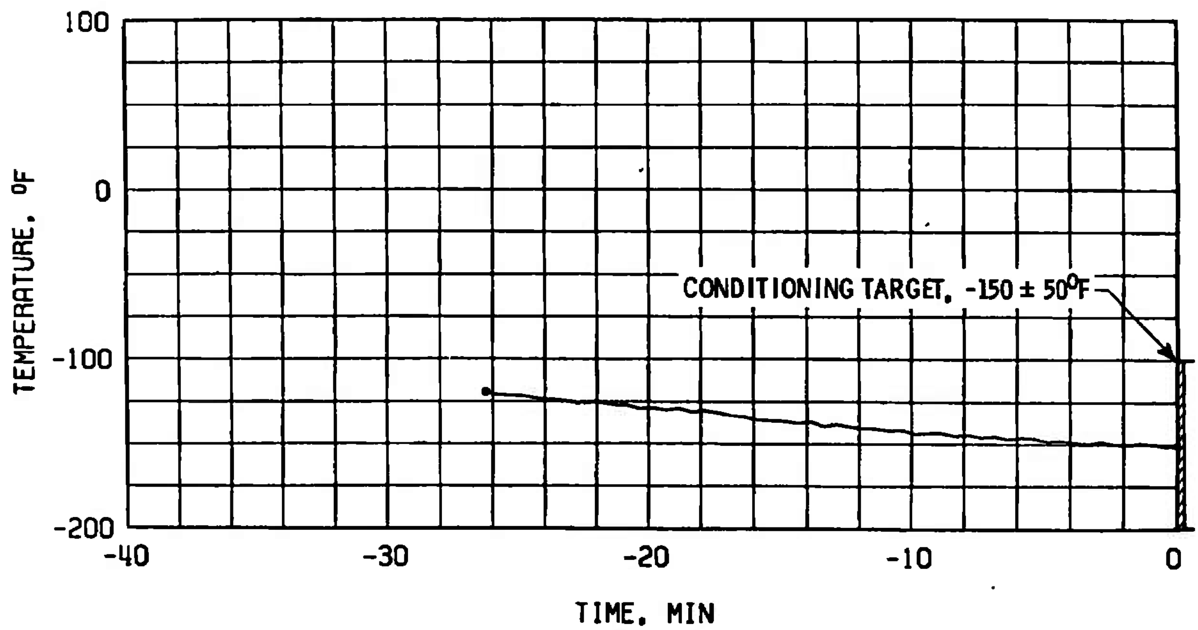
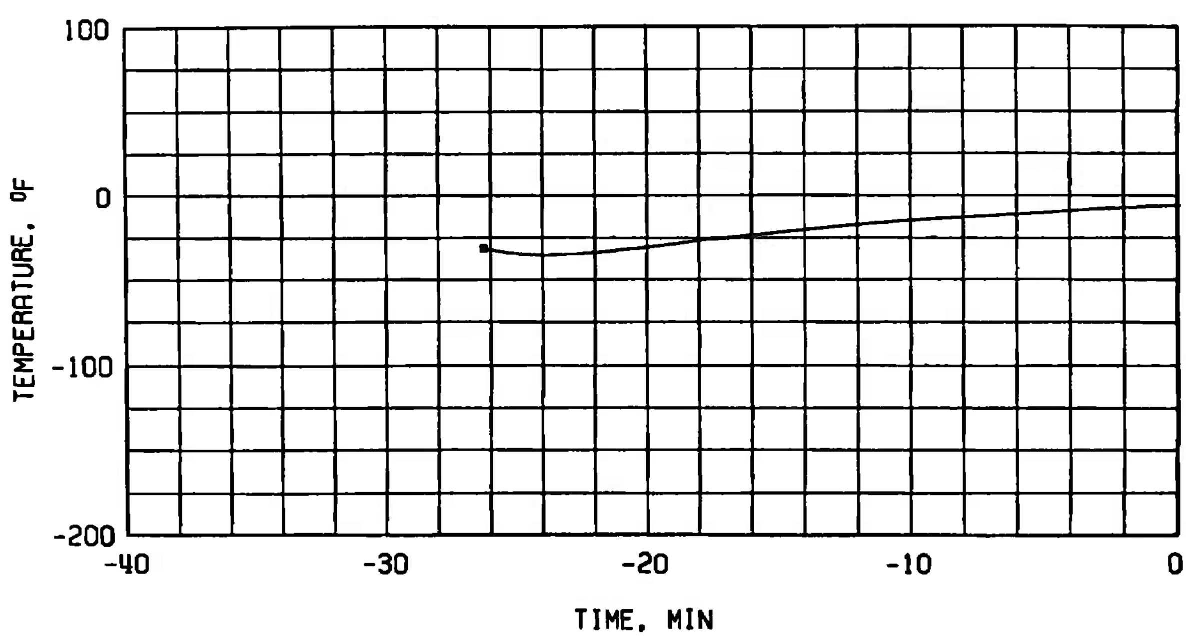


Fig. 24 Engine Ambient and Combustion Chamber Pressure, Firing 34D

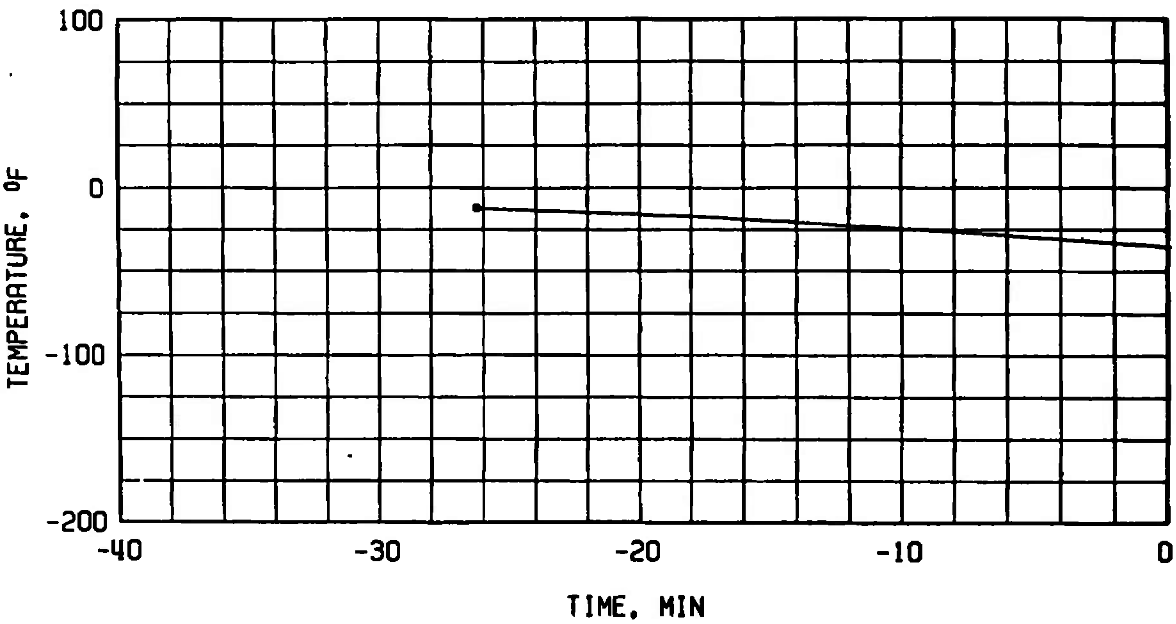


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

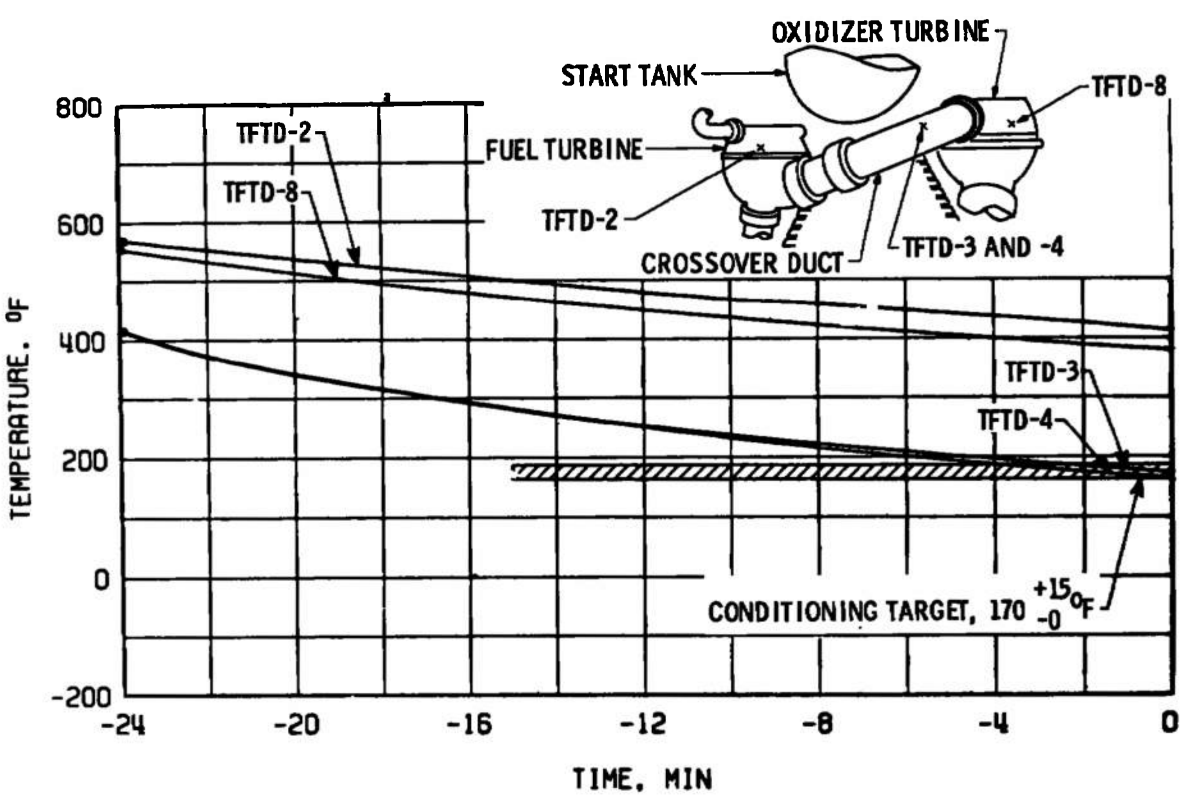


b. Gas Generator Body Temperature, TGGVRS

Fig. 25 Thermal Conditioning History of Engine Components, Firing 34E

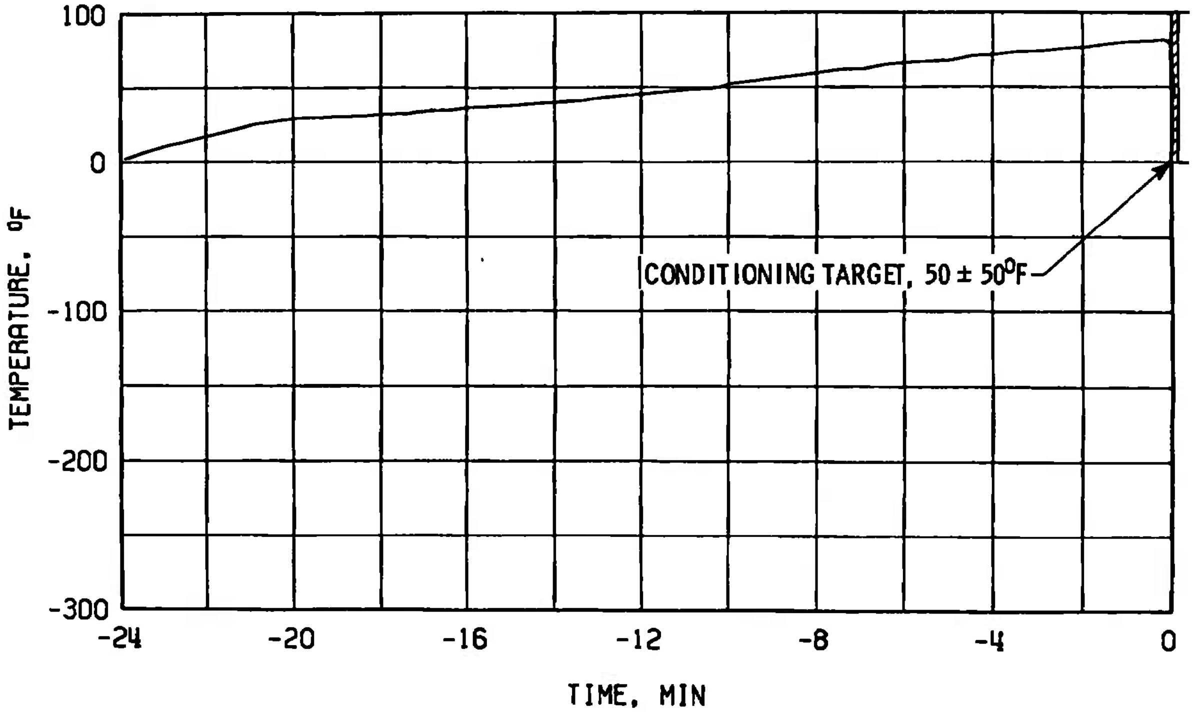


c. Start Tank Discharge Valve Opening Control, TSTDVOC

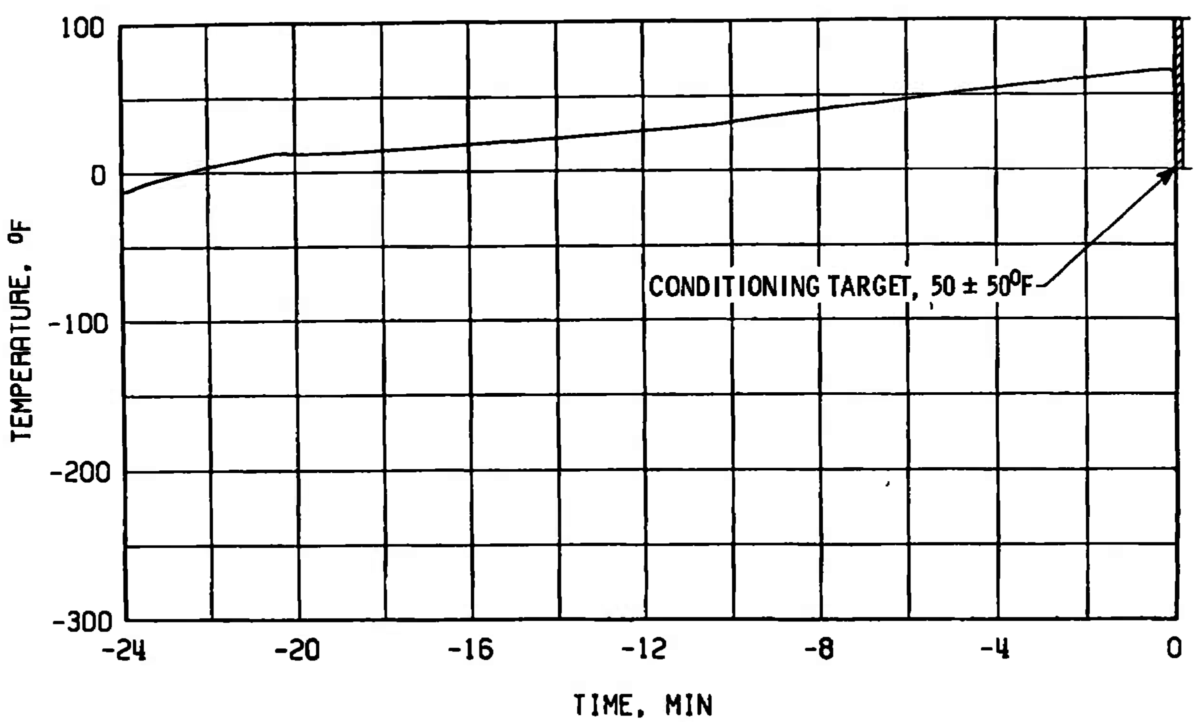


d. Crossover Duct, TFTD

Fig. 25 Continued

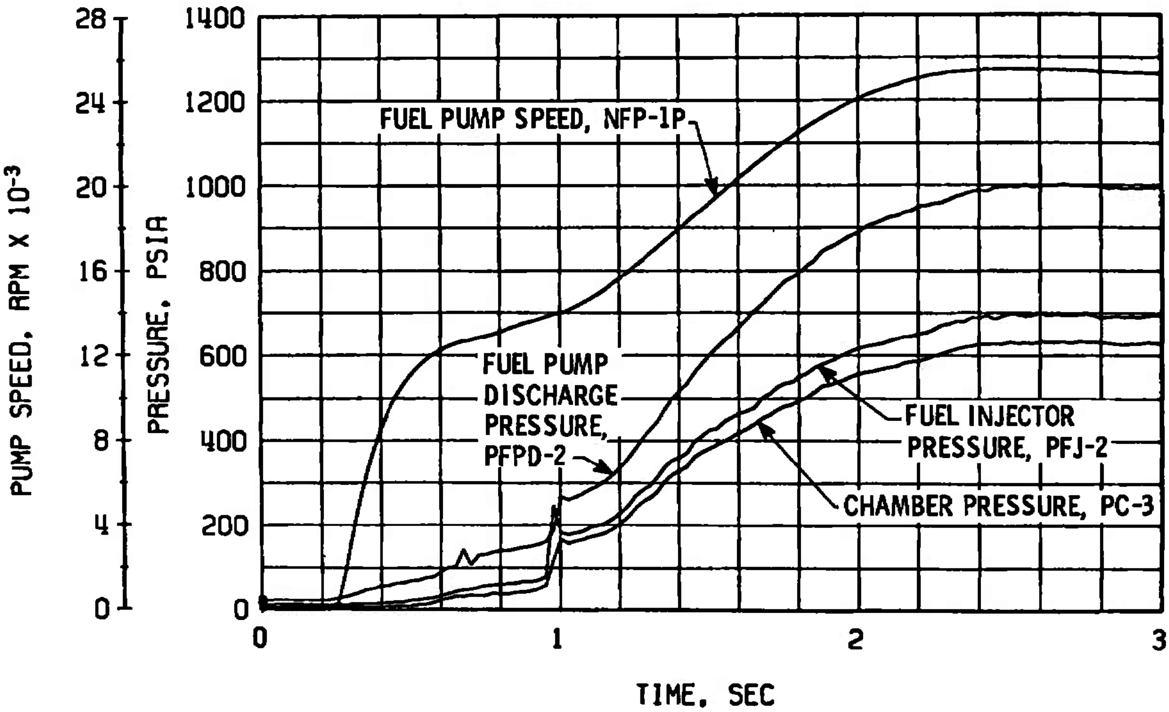


e. Thrust Chamber Throat, TTC-1P

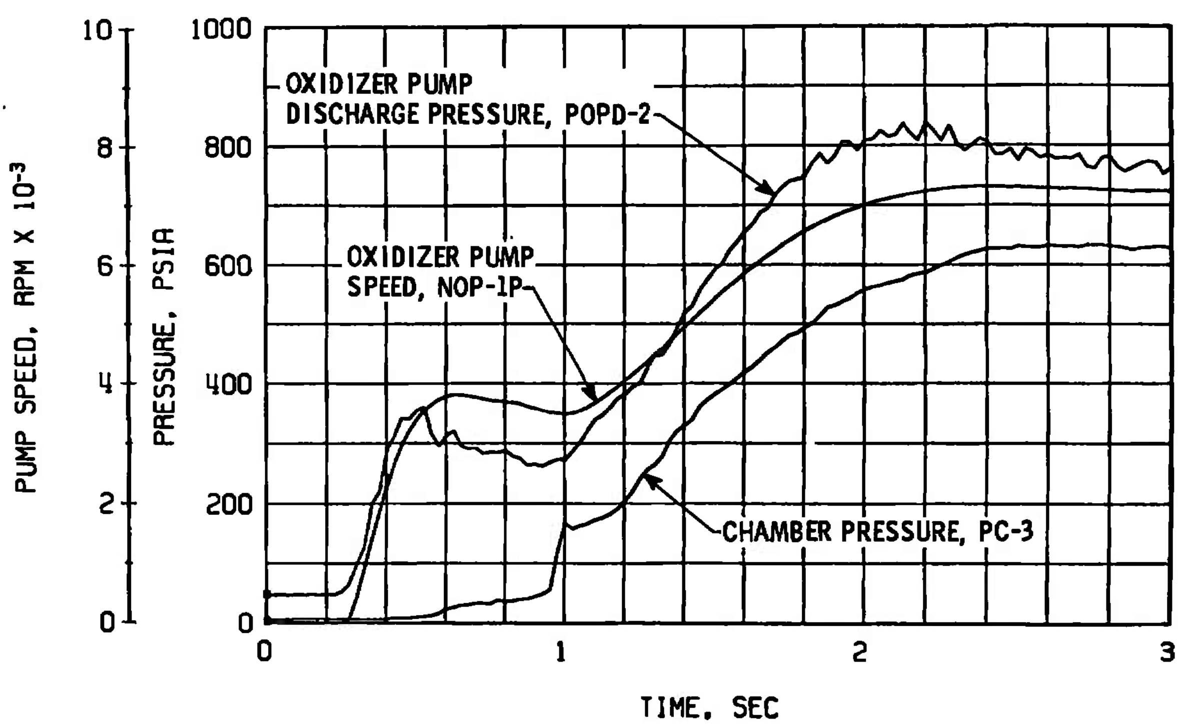


f. Thrust Chamber Throat, TTC-2

Fig. 25 Concluded

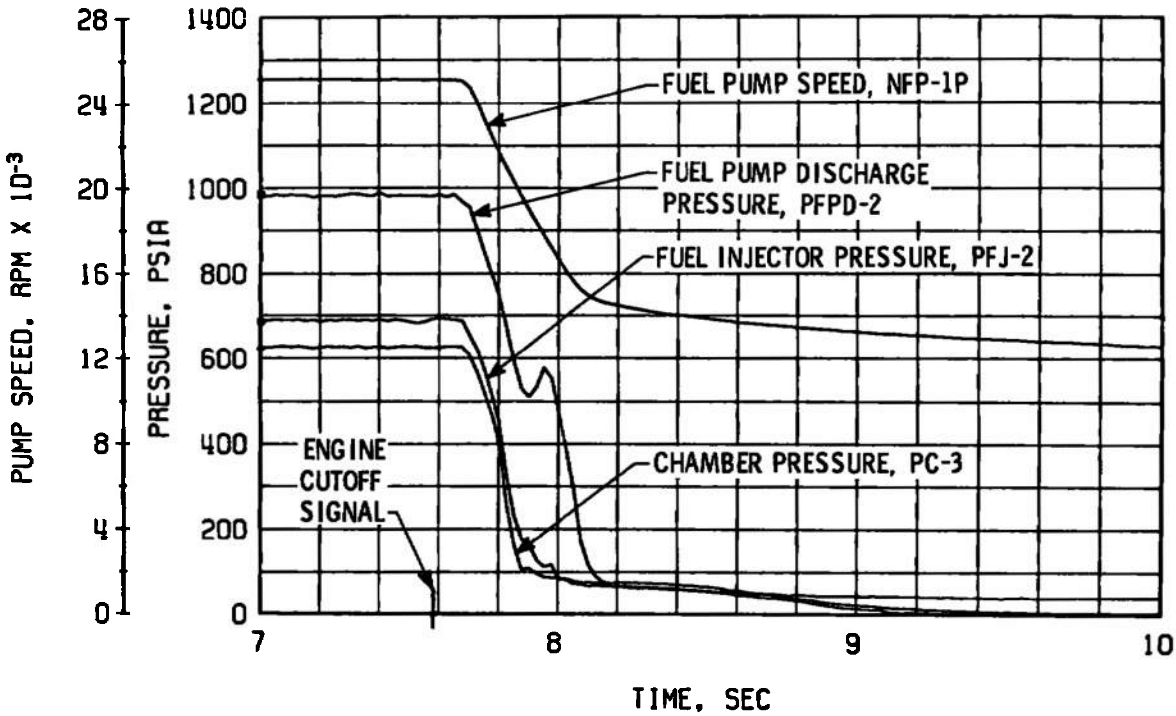


a. Thrust Chamber Fuel System, Start

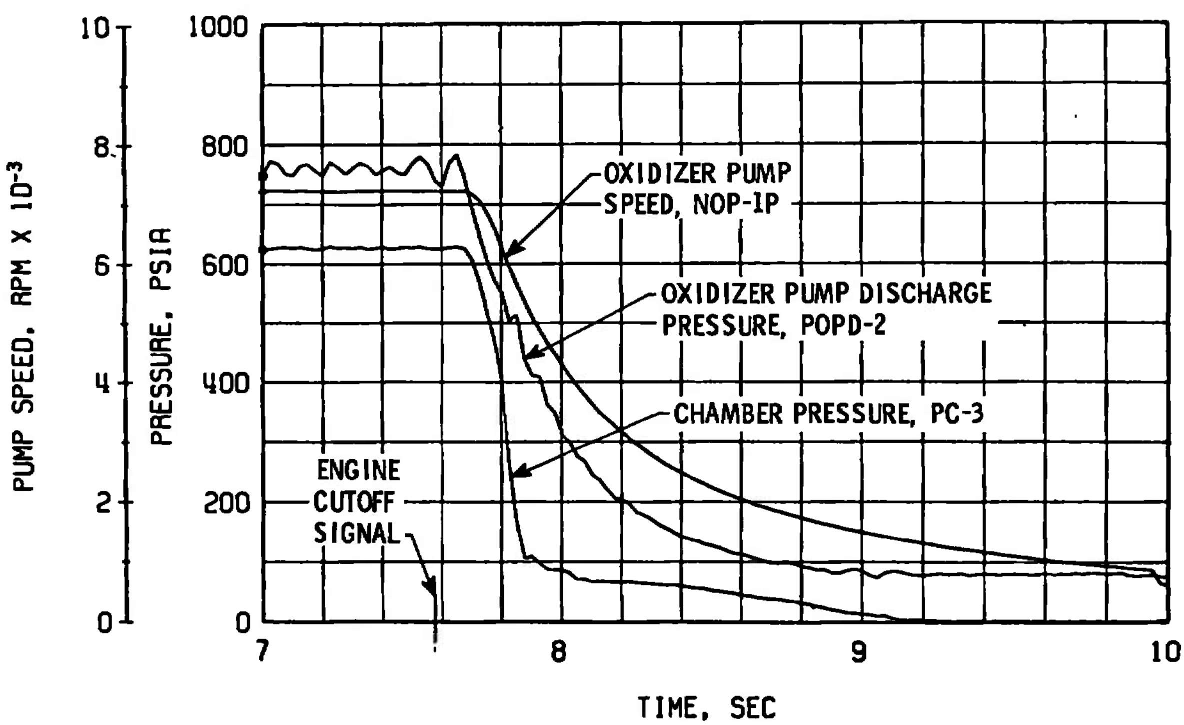


b. Thrust Chamber Oxidizer System, Start

Fig. 26 Engine Transient Operation, Firing 34E

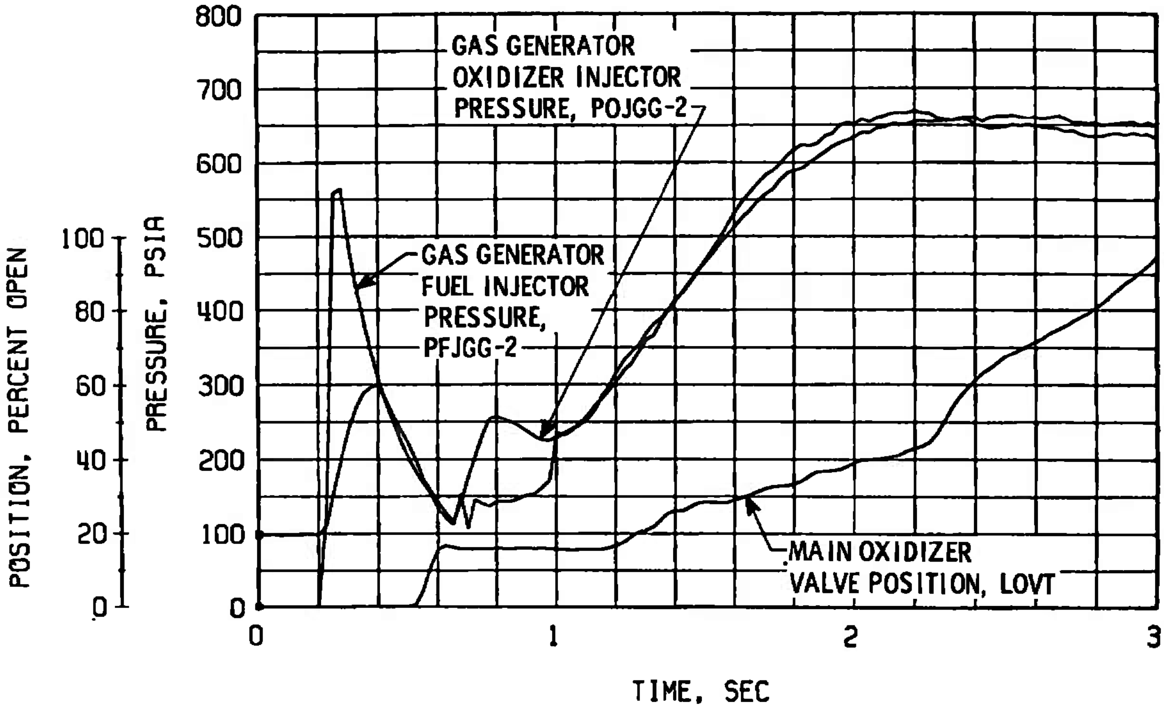


c. Thrust Chamber Fuel System, Shutdown

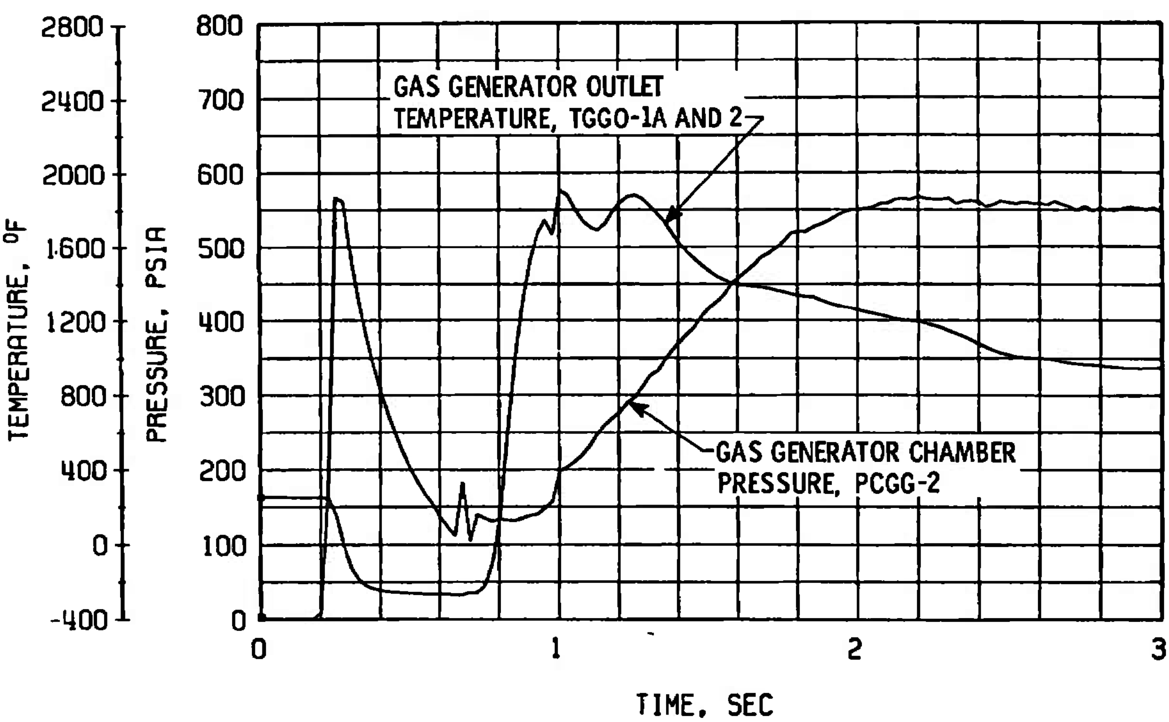


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 26 Continued

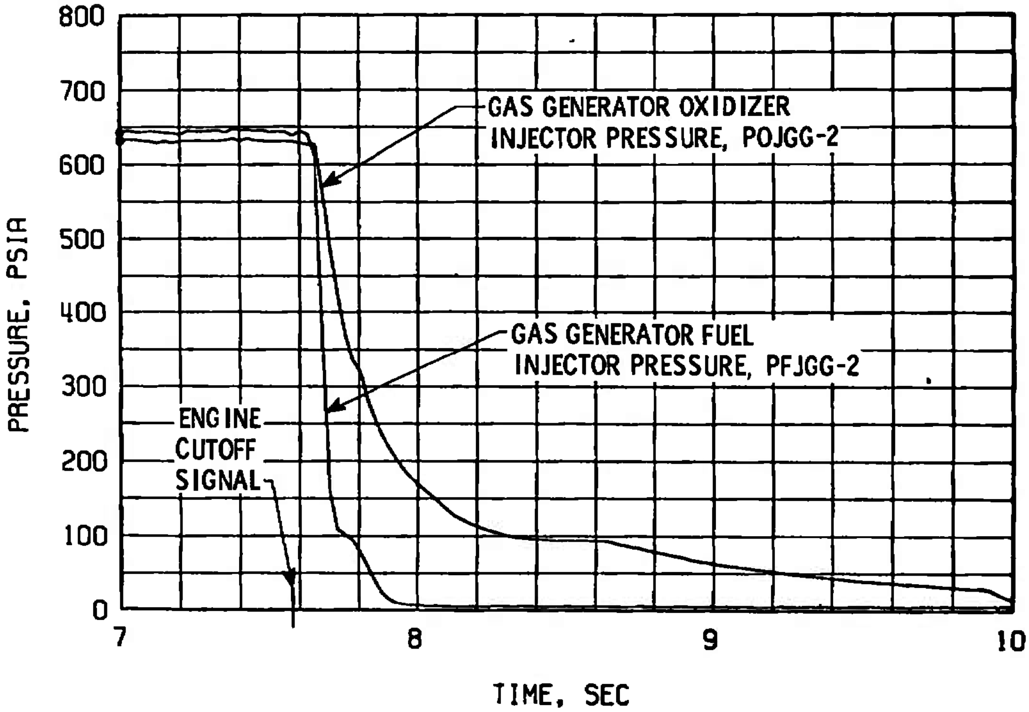


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

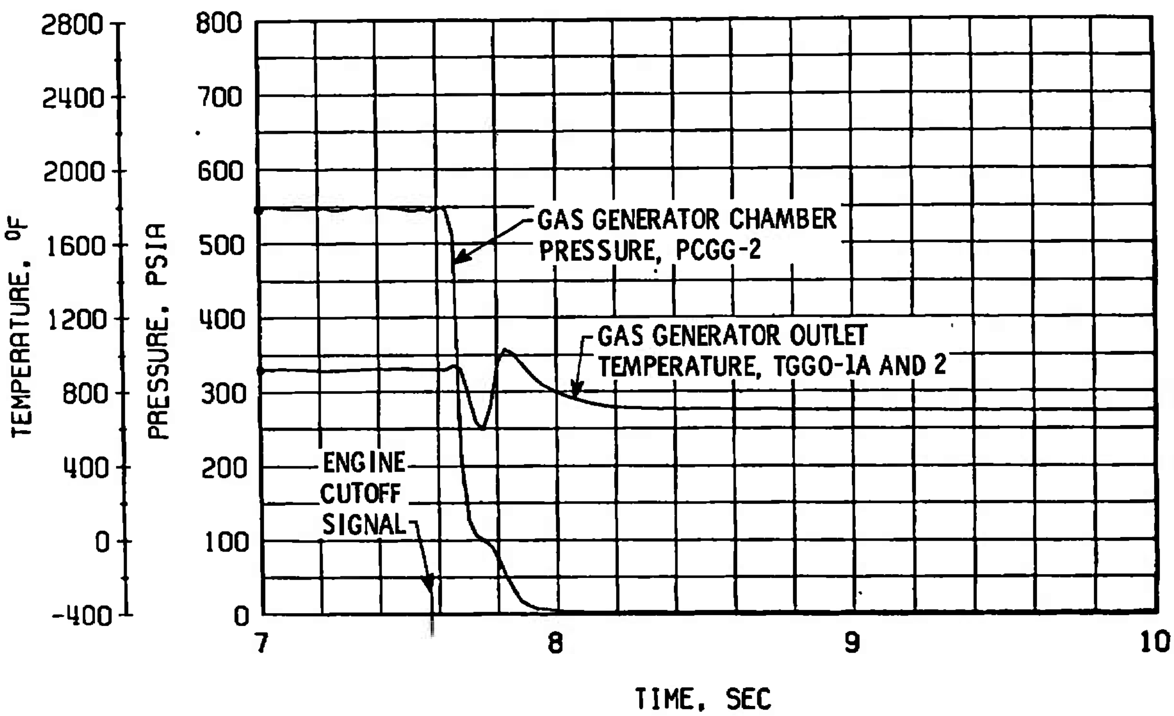


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 26 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 26 Concluded

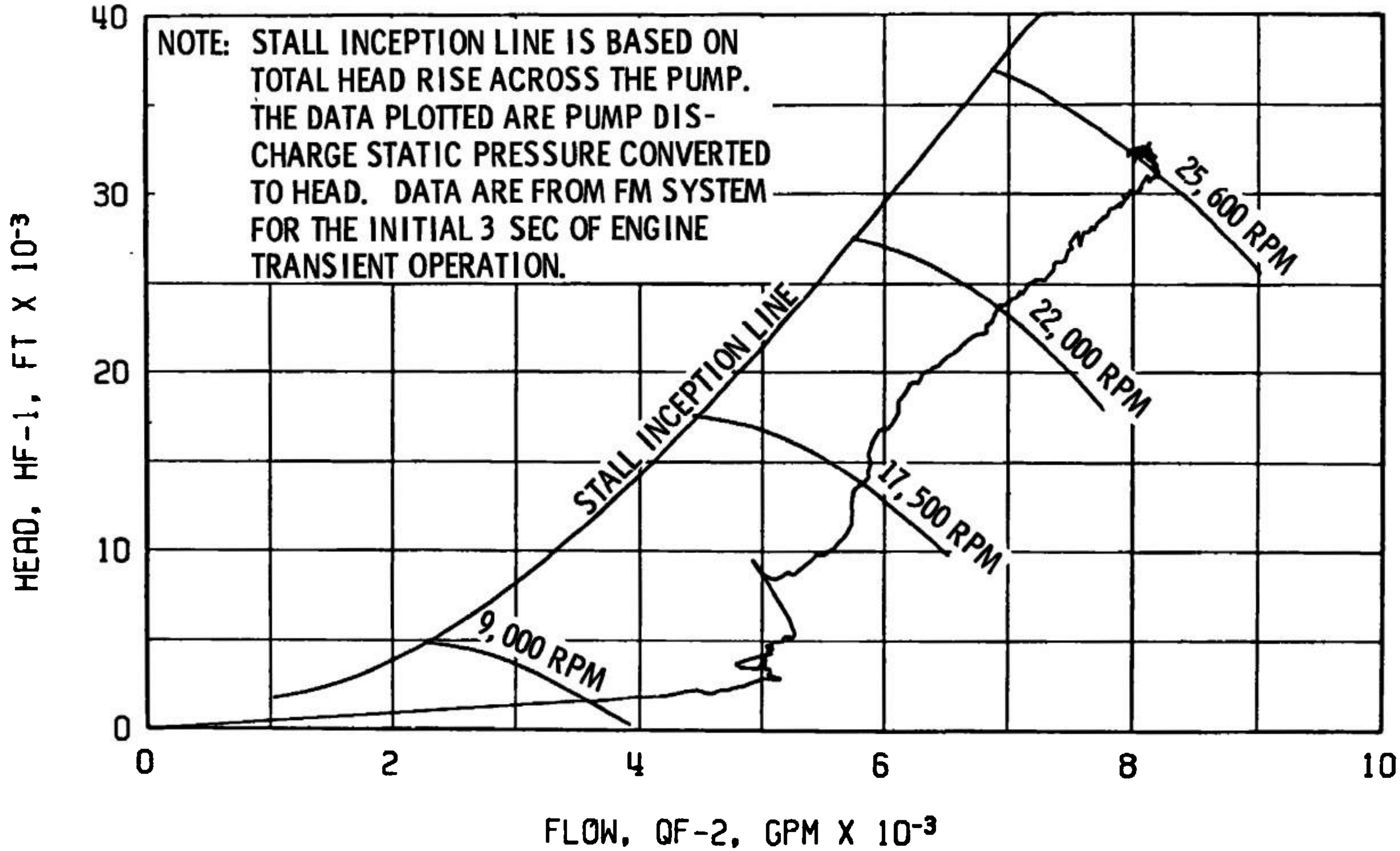


Fig. 27 Fuel Pump Start Transient Performance, Firing 34E

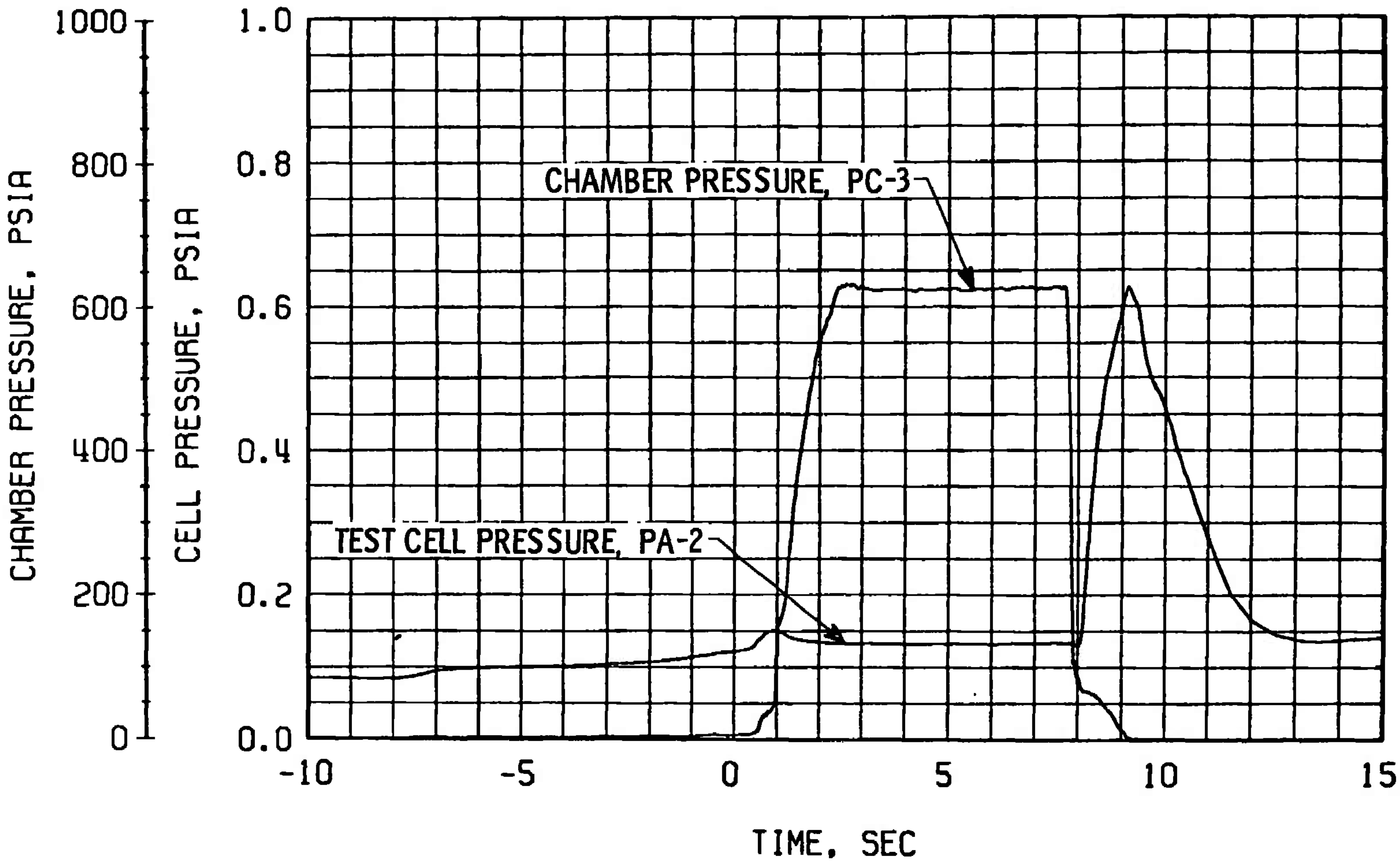
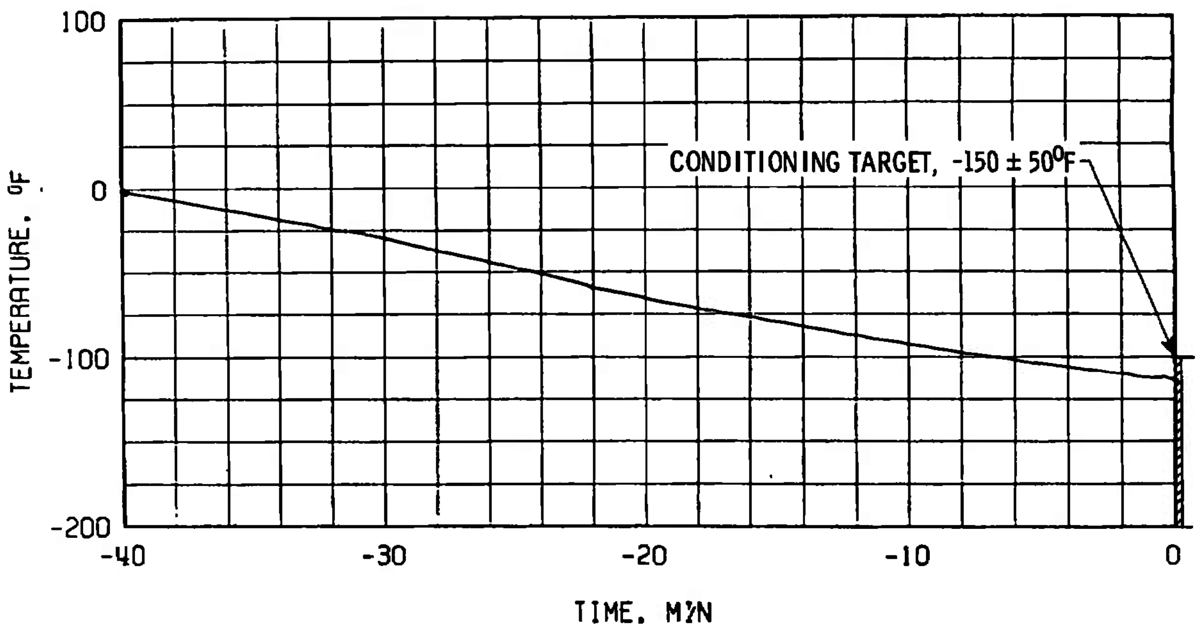
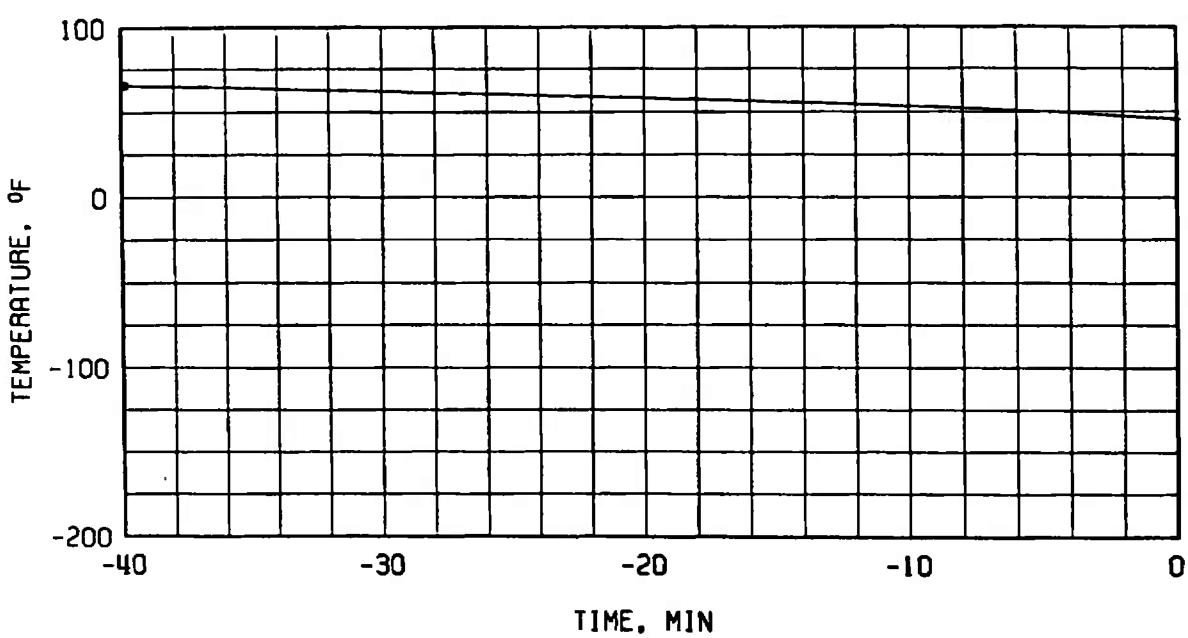


Fig. 28 Engine Ambient and Combustion Chamber Pressure, Firing 34E

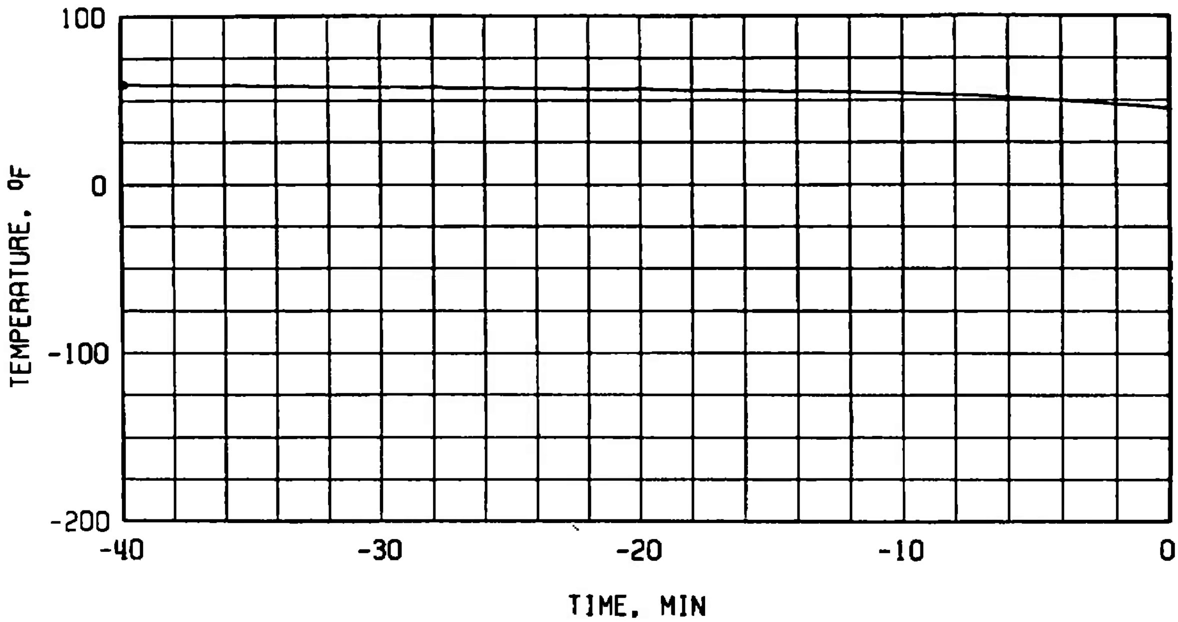


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

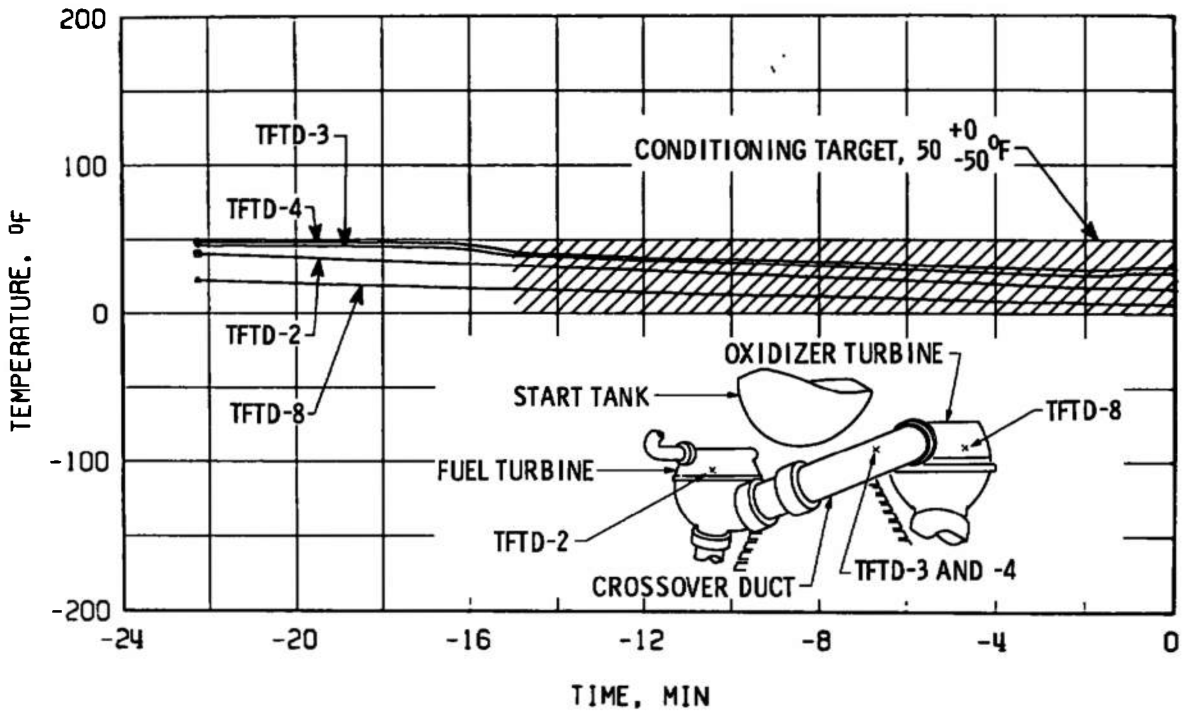


b. Gas Generator Body Temperature, TGGVRS

Fig. 29 Thermal Conditioning History of Engine Components, Firing 35A

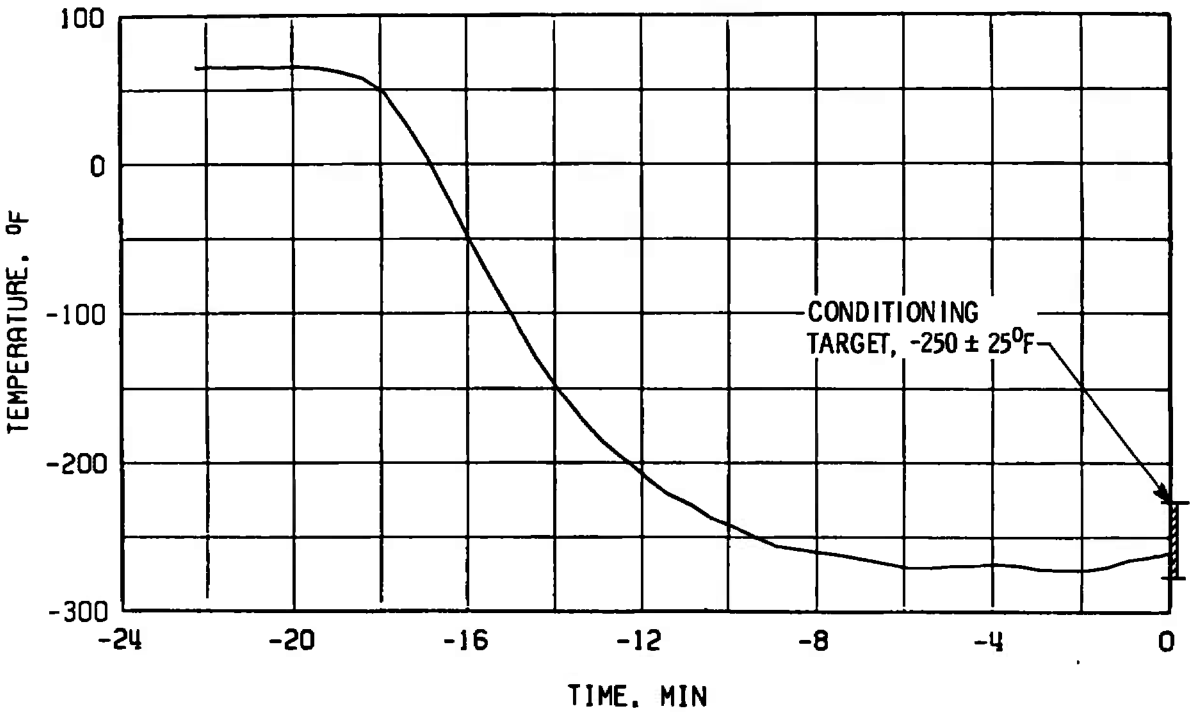


c. Start Tank Discharge Valve Opening Control Temperature, TSTDVOC

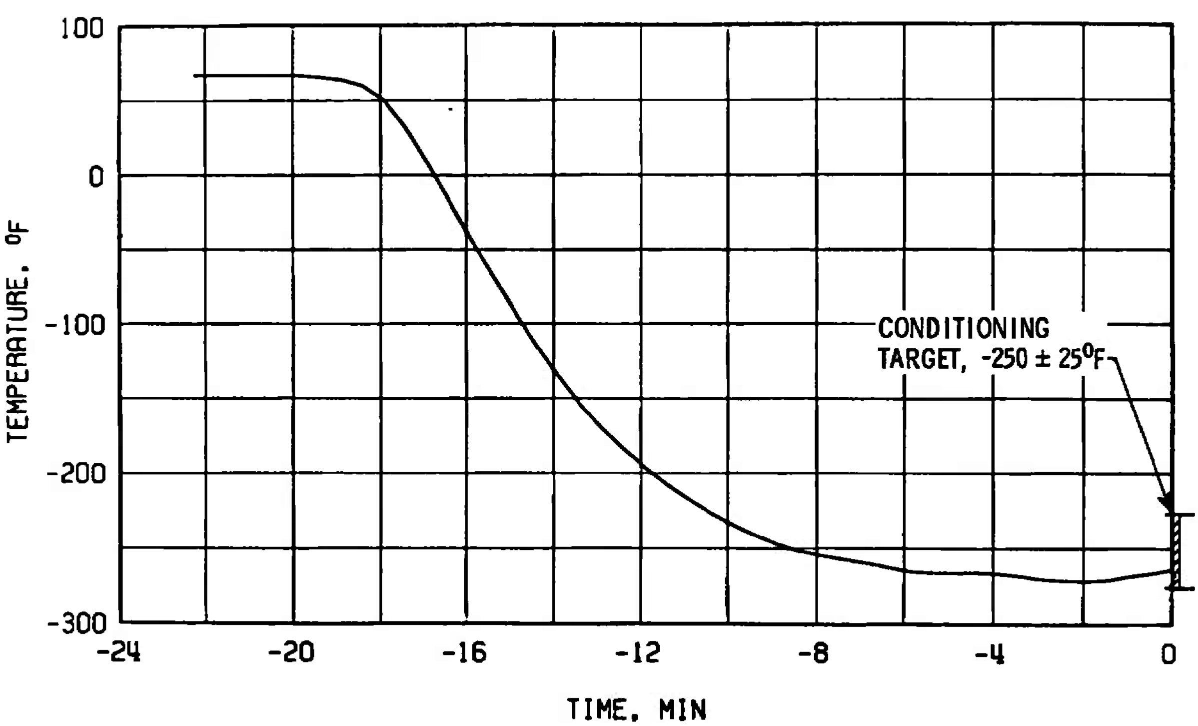


d. Crossover Duct, TFTD

Fig. 29 Continued

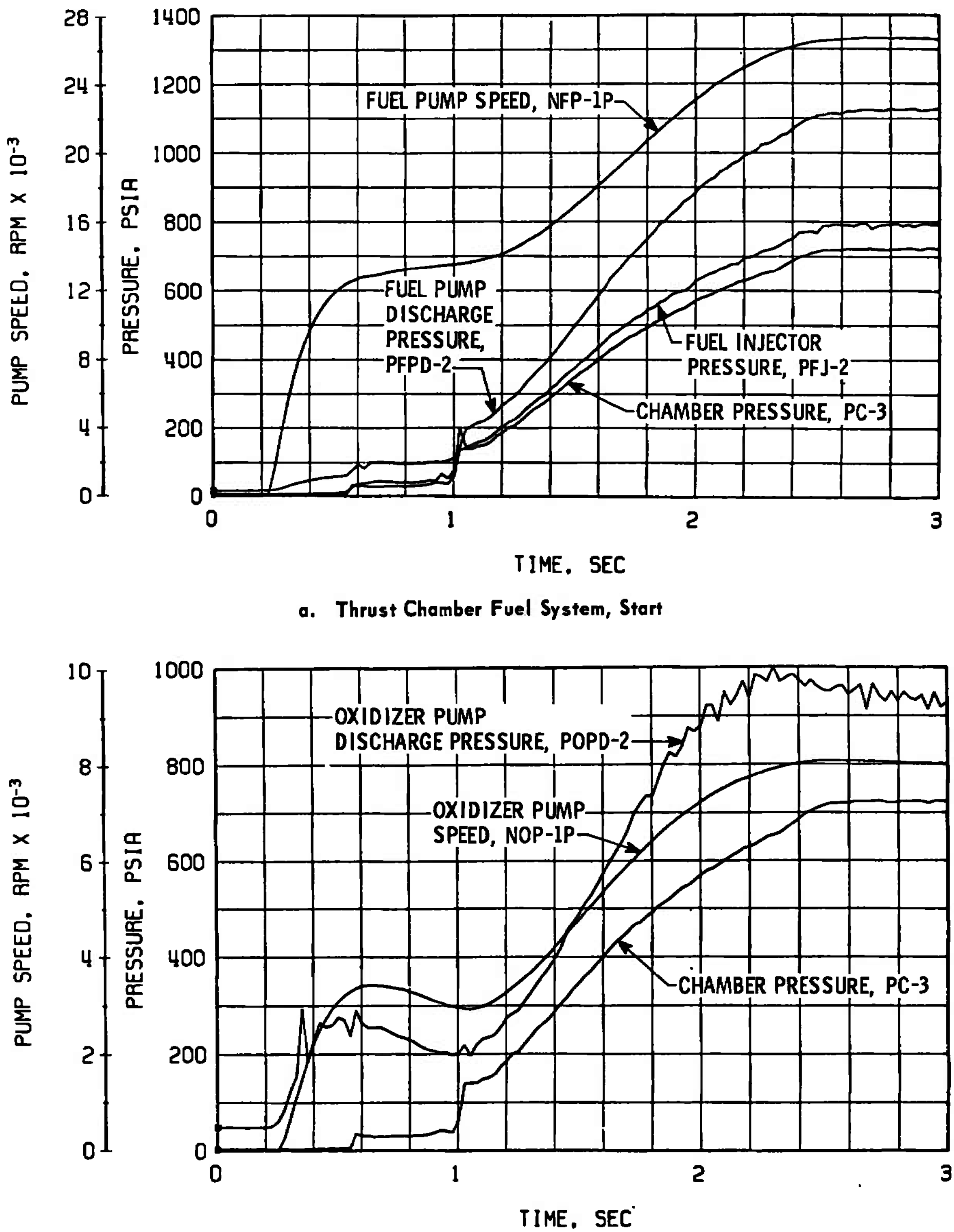


e. Thrust Chamber Throat, TTC-1P



f. Thrust Chamber Throat, TTC-2

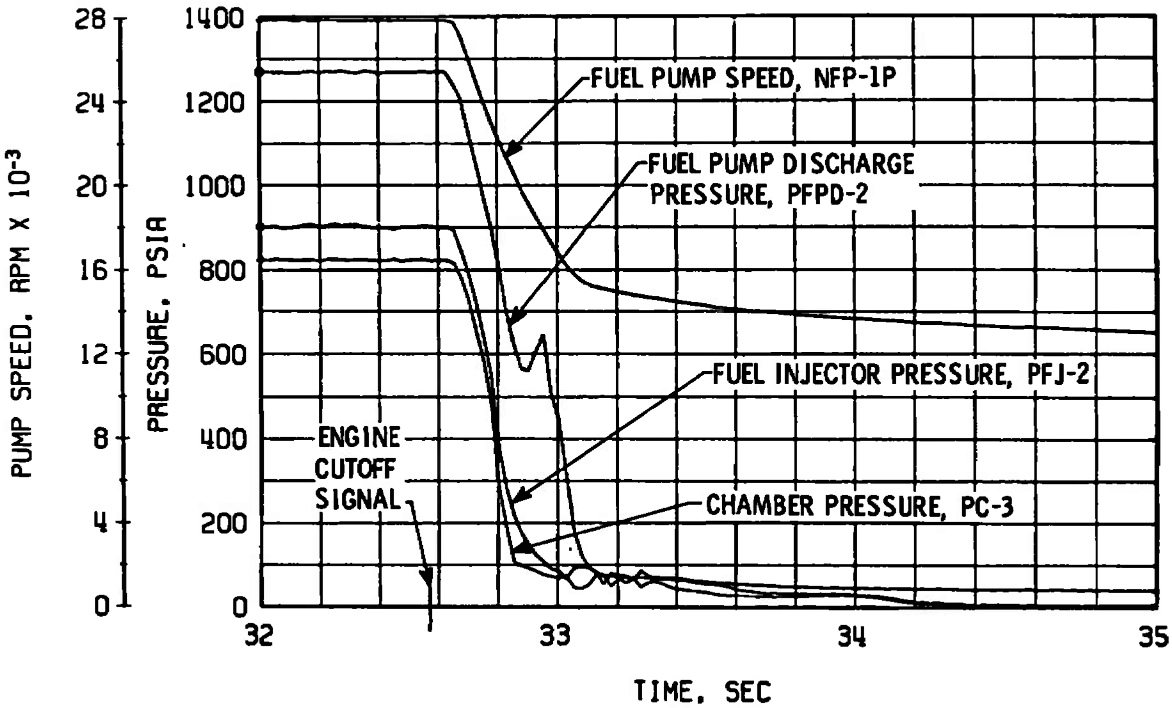
Fig. 29 Concluded



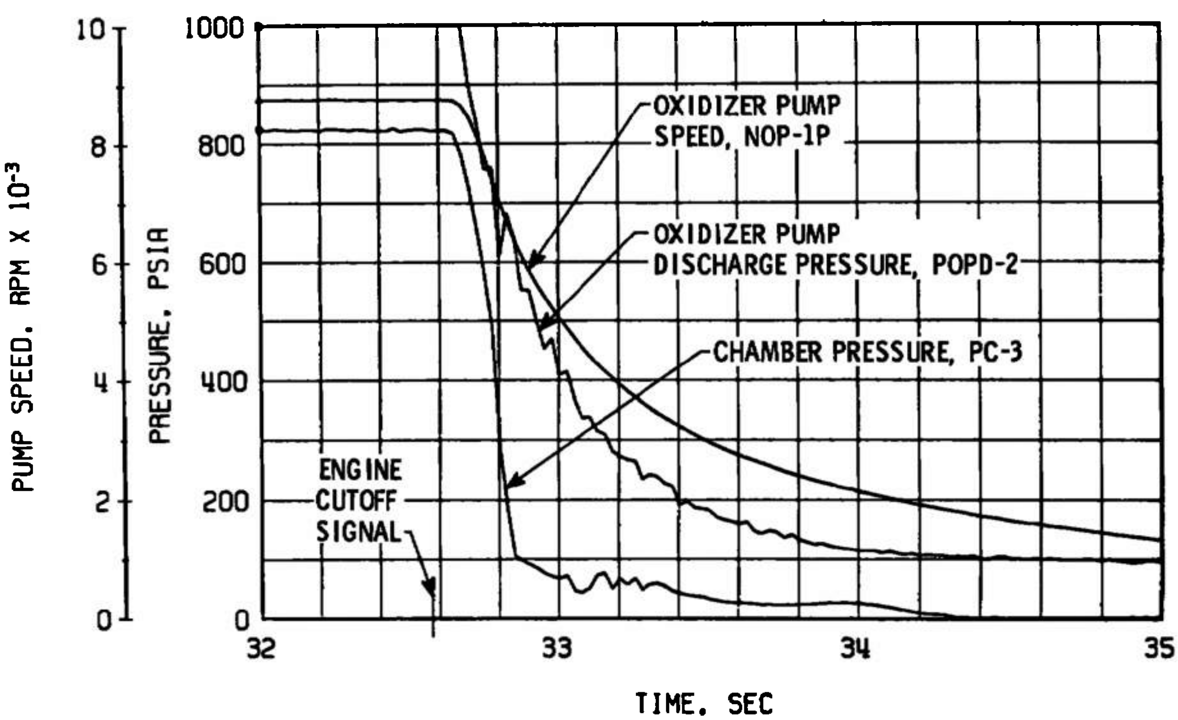
a. Thrust Chamber Fuel System, Start

b. Thrust Chamber Oxidizer System, Start

Fig. 30 Engine Transient Operation, Firing 35A

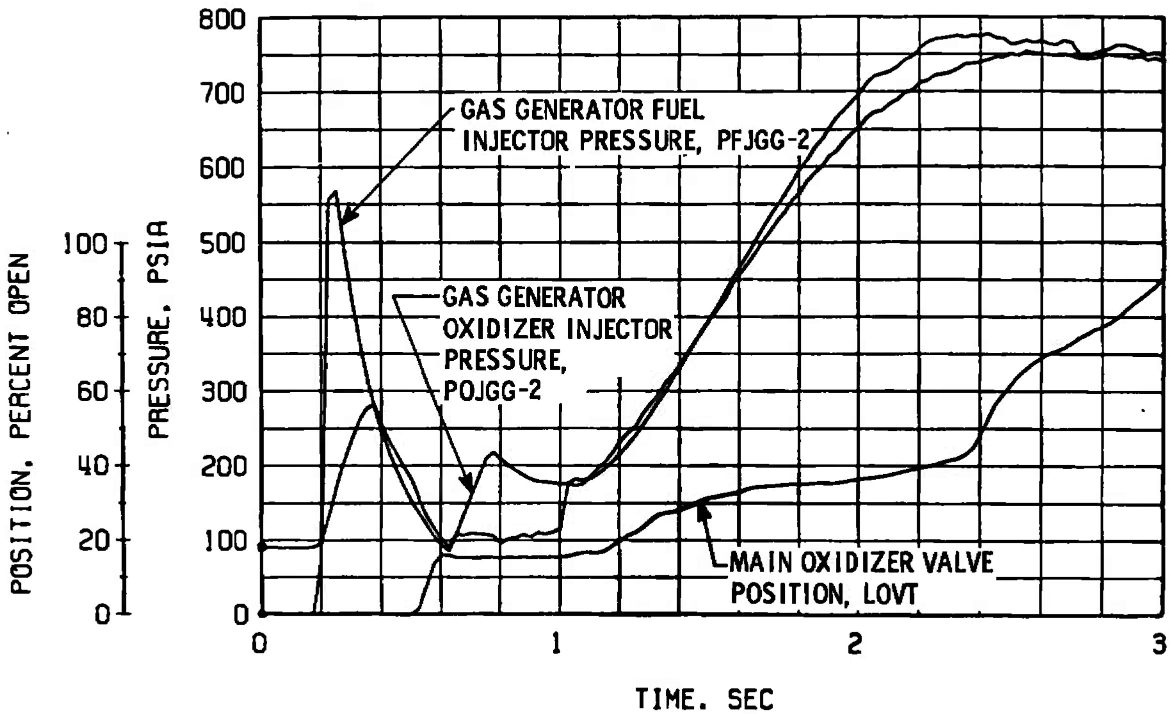


c. Thrust Chamber Fuel System, Shutdown

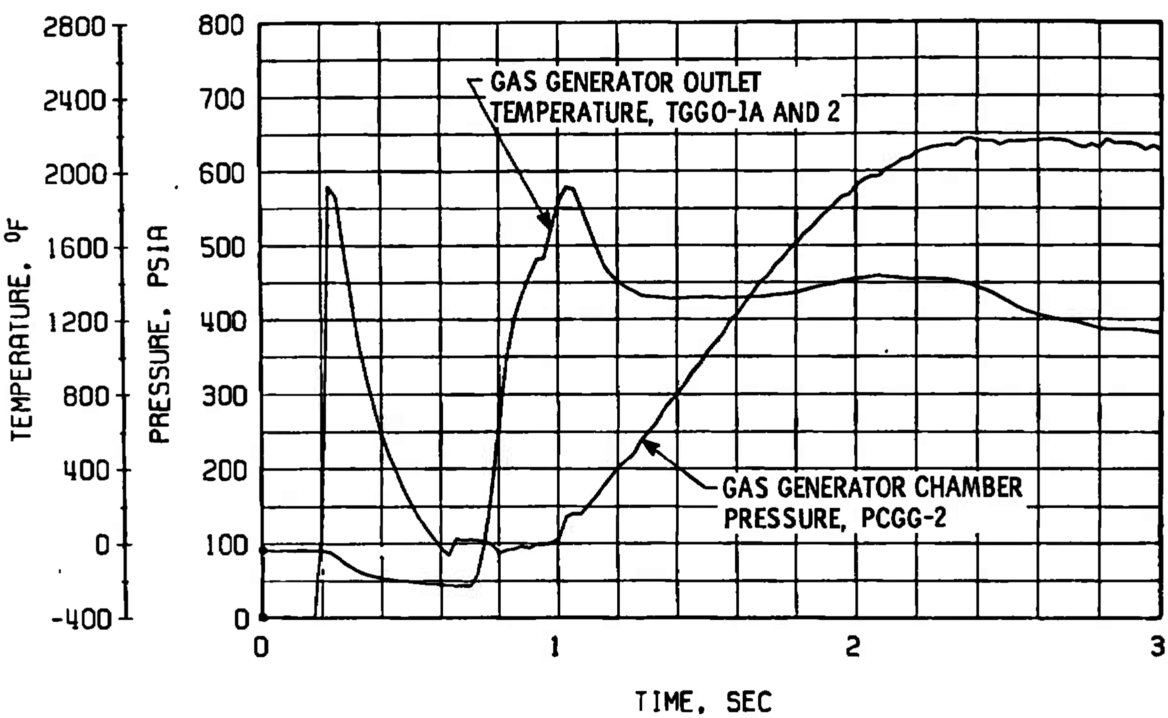


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 30 Continued

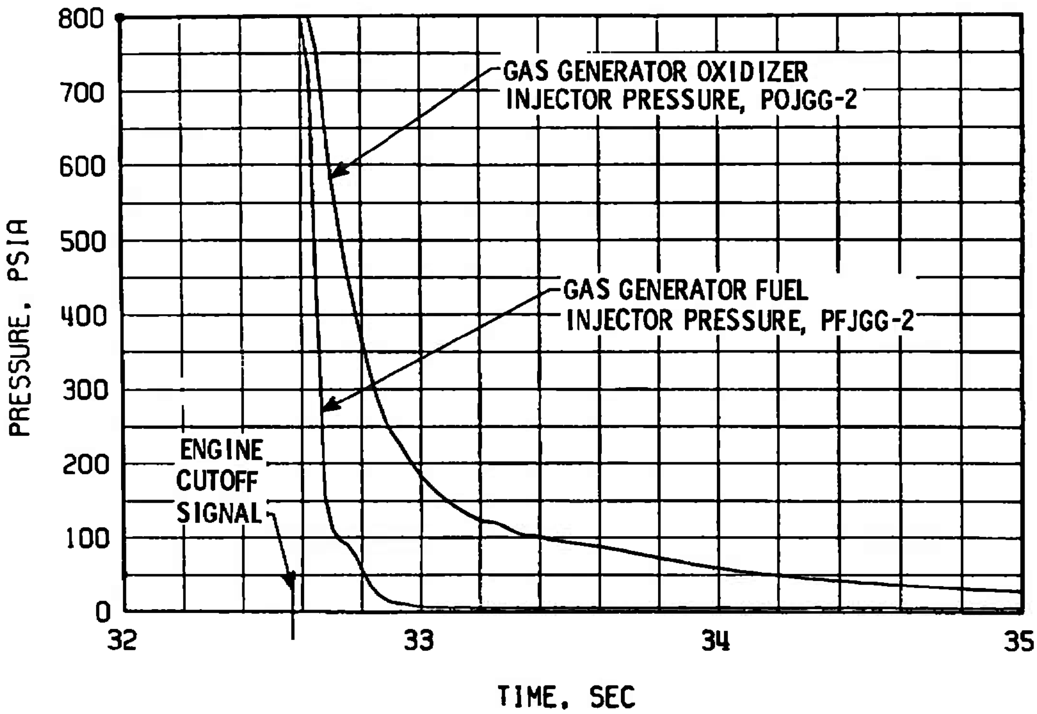


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

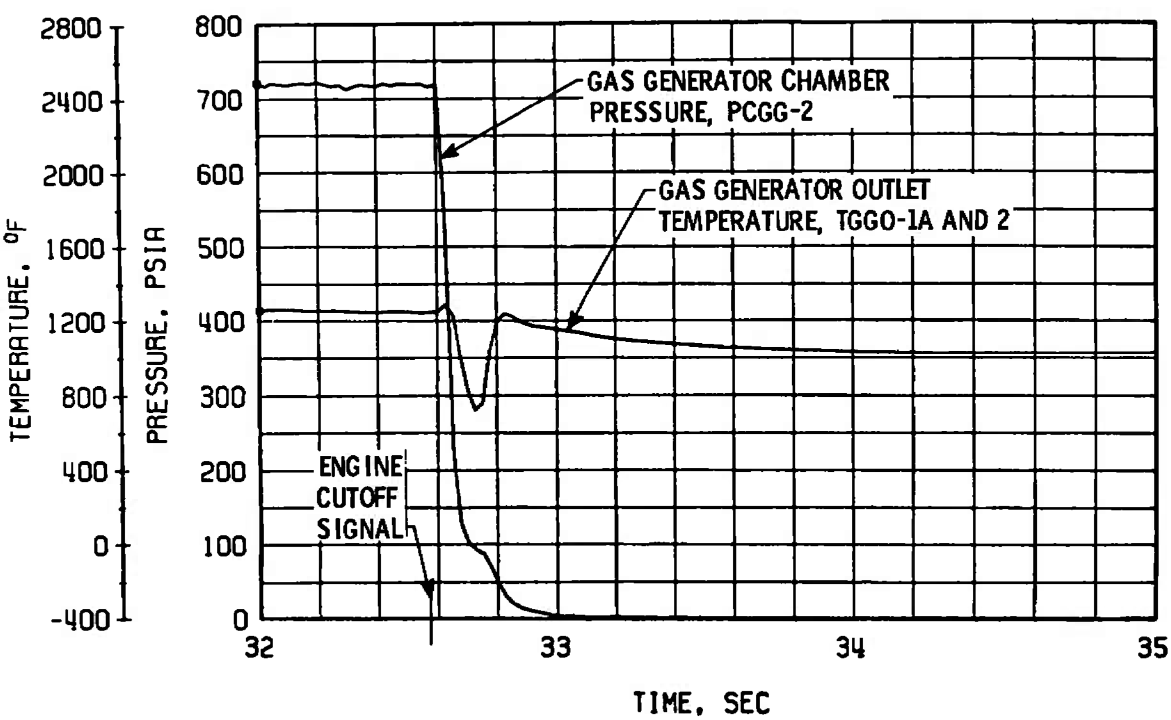


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 30 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 30 Concluded

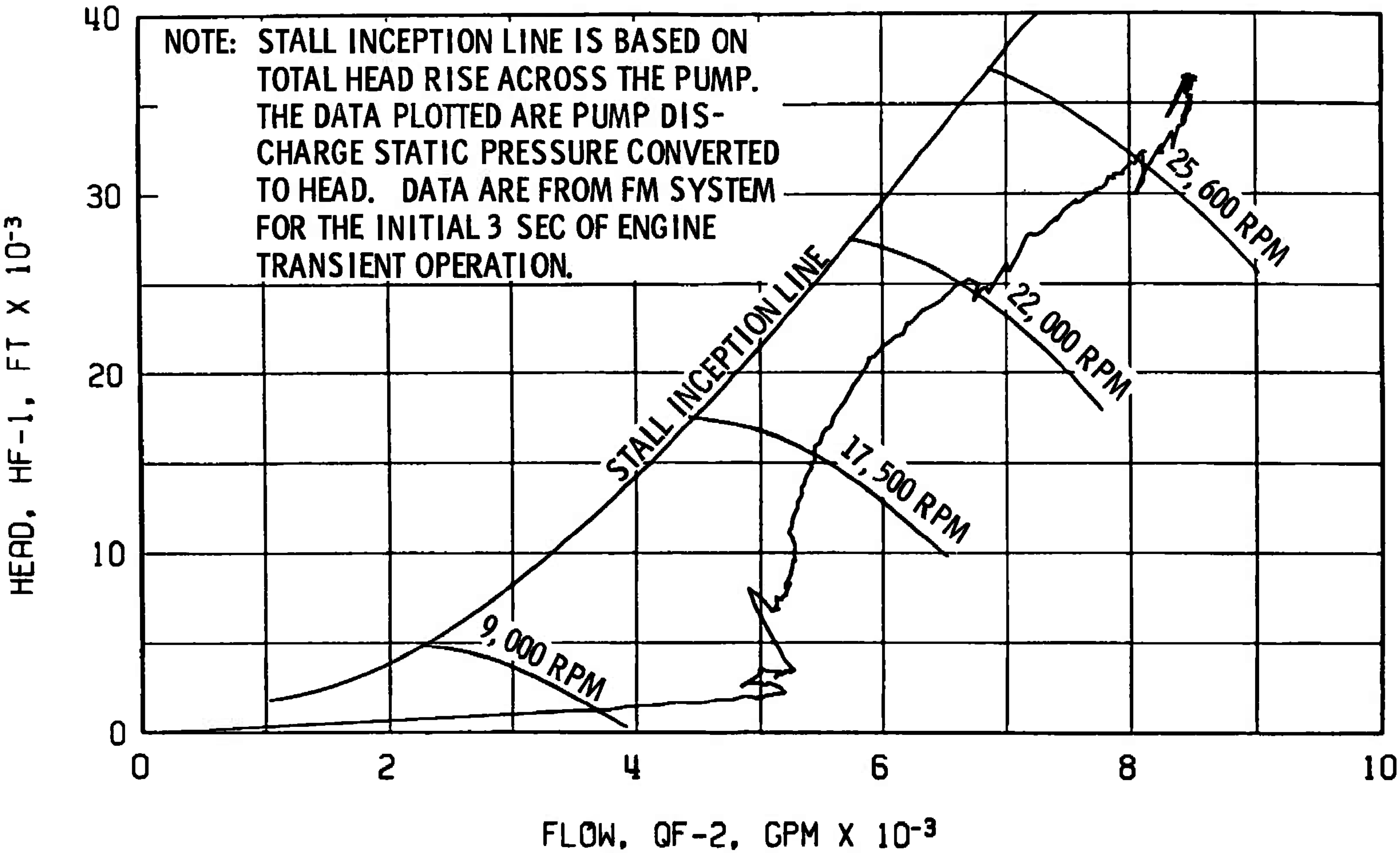


Fig. 31 Fuel Pump Start Transient Performance, Firing 35A

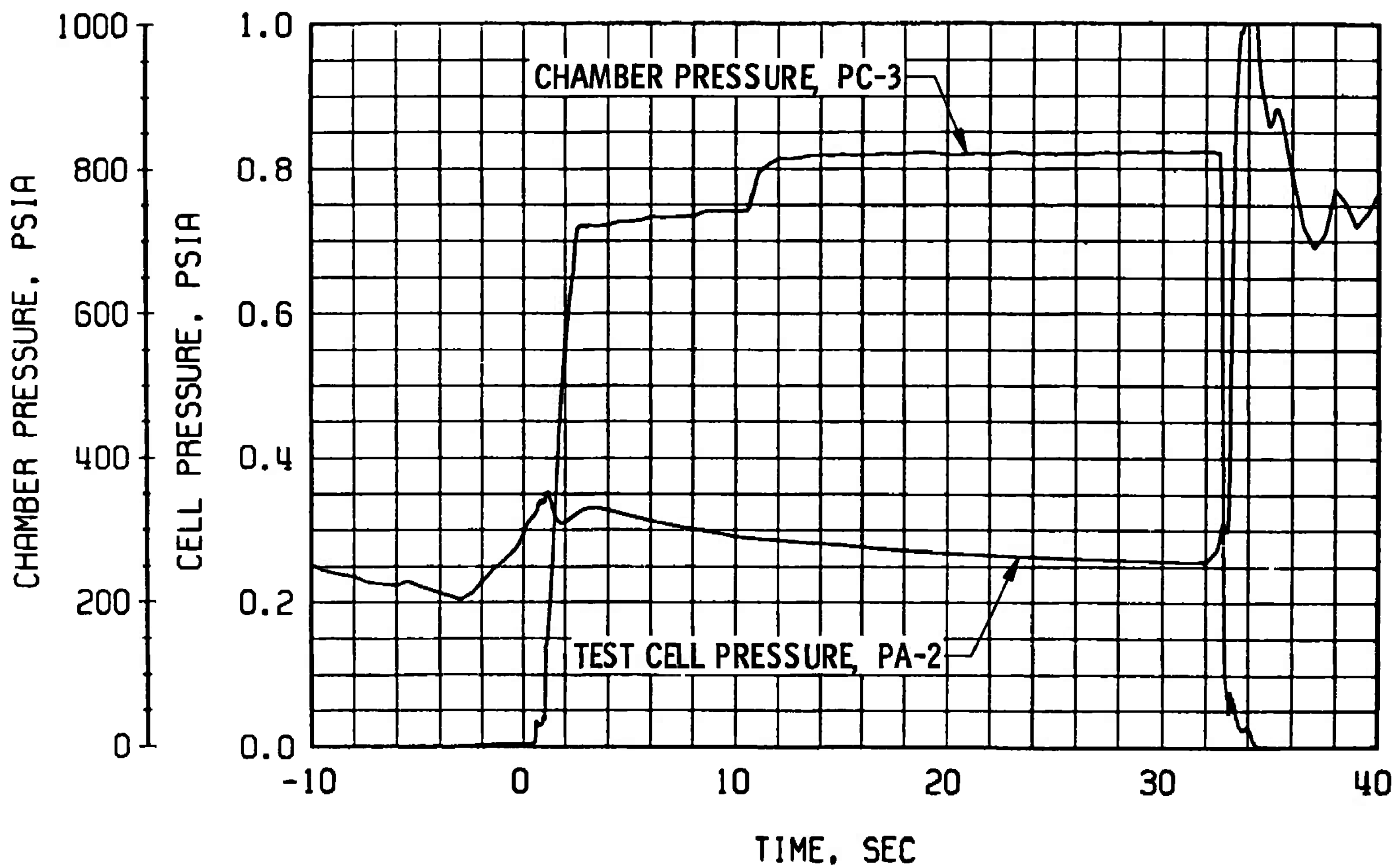
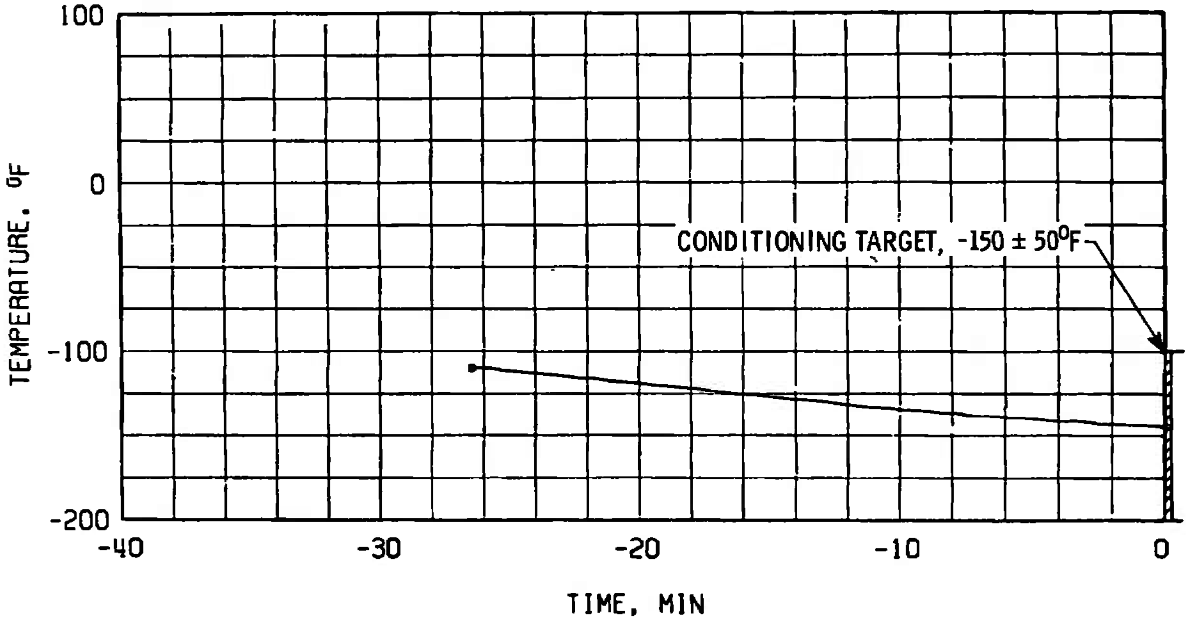
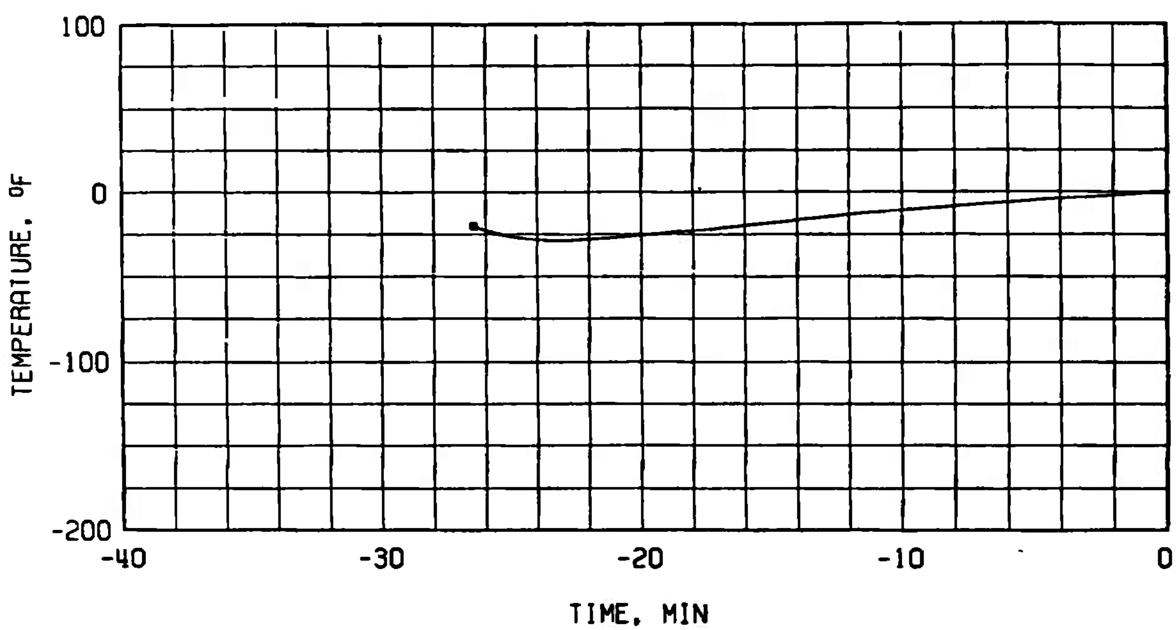


Fig. 32 Engine Ambient and Combustion Chamber Pressure, Firing 35A

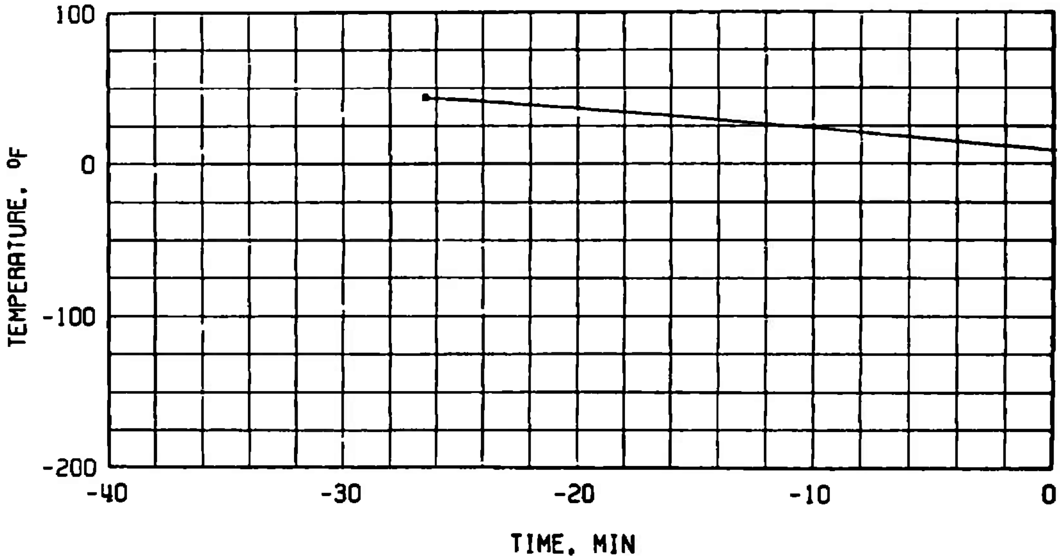


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

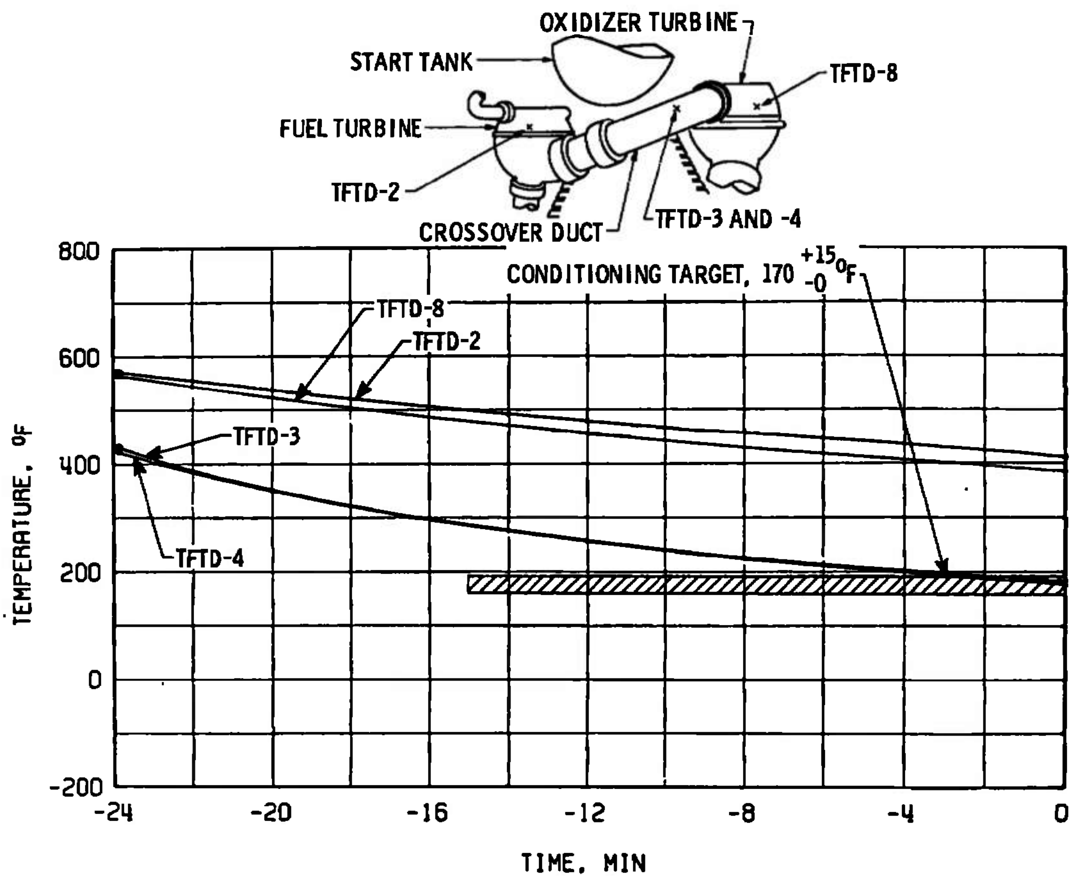


b. Gas Generator Body Temperature, TGGVRS

Fig. 33 Thermal Conditioning History of Engine Components, Firing 35B

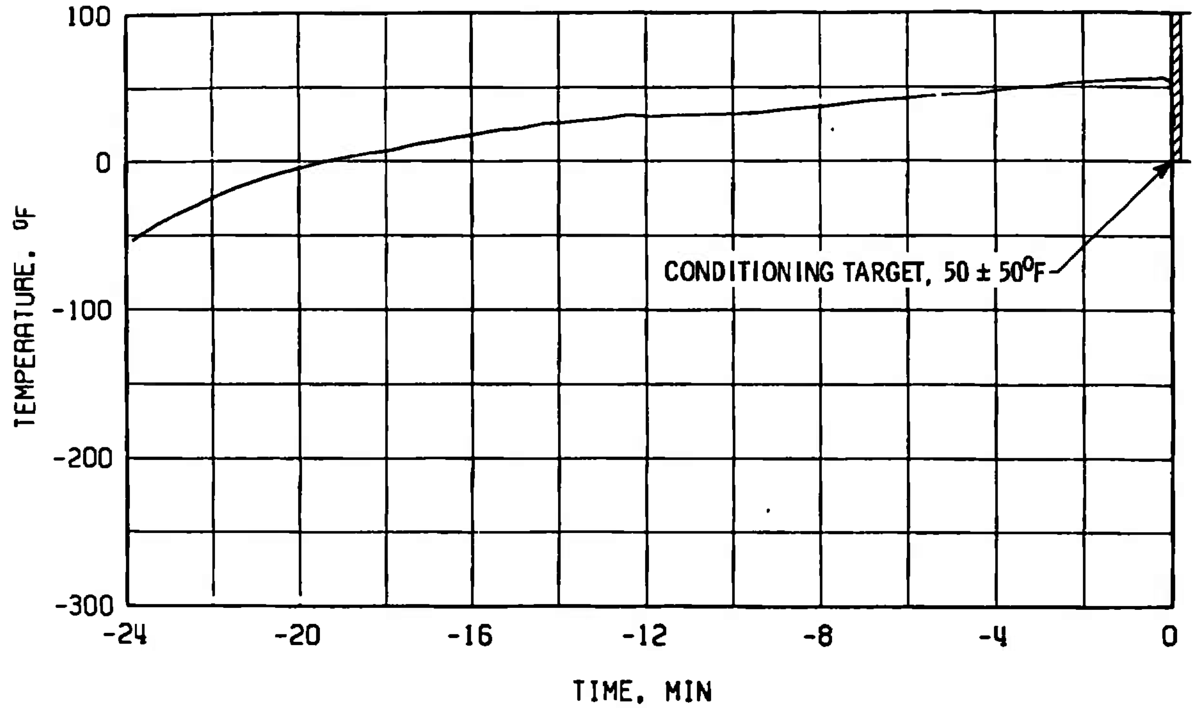


c. Start Tank Discharge Valve Opening Control Temperature, TSTDVOC

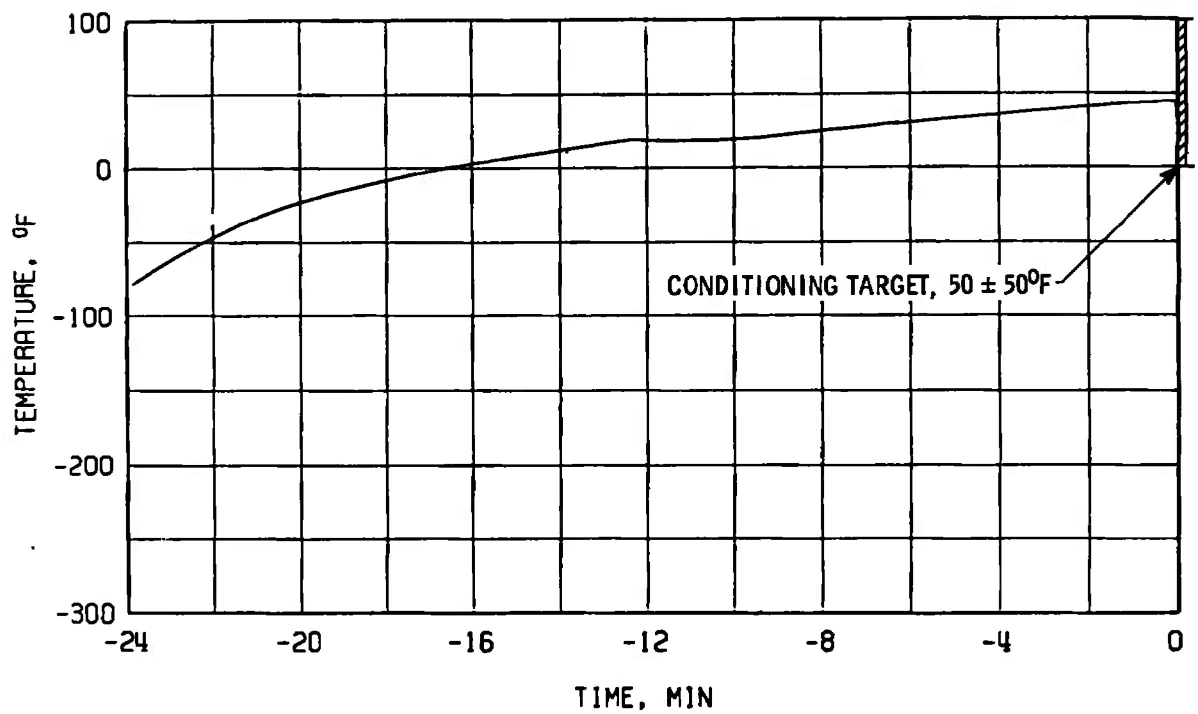


d. Crossover Duct, TFTD

Fig. 33 Continued

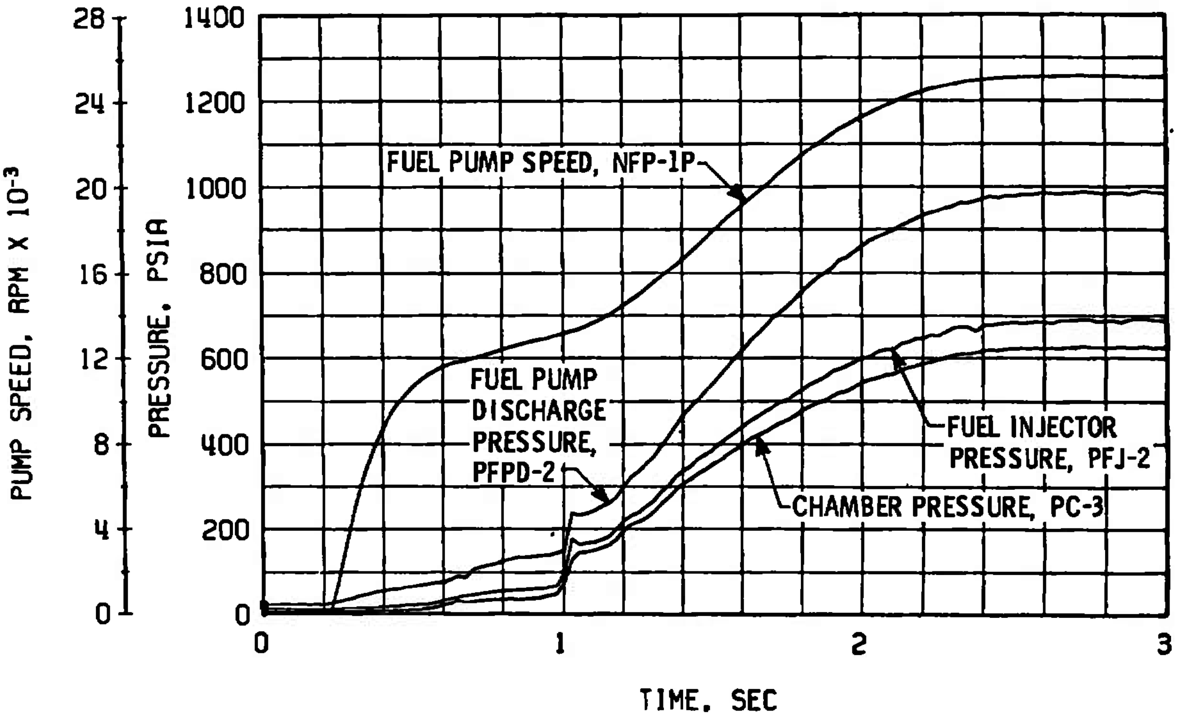


e. Thrust Chamber Throat, TTC-1P

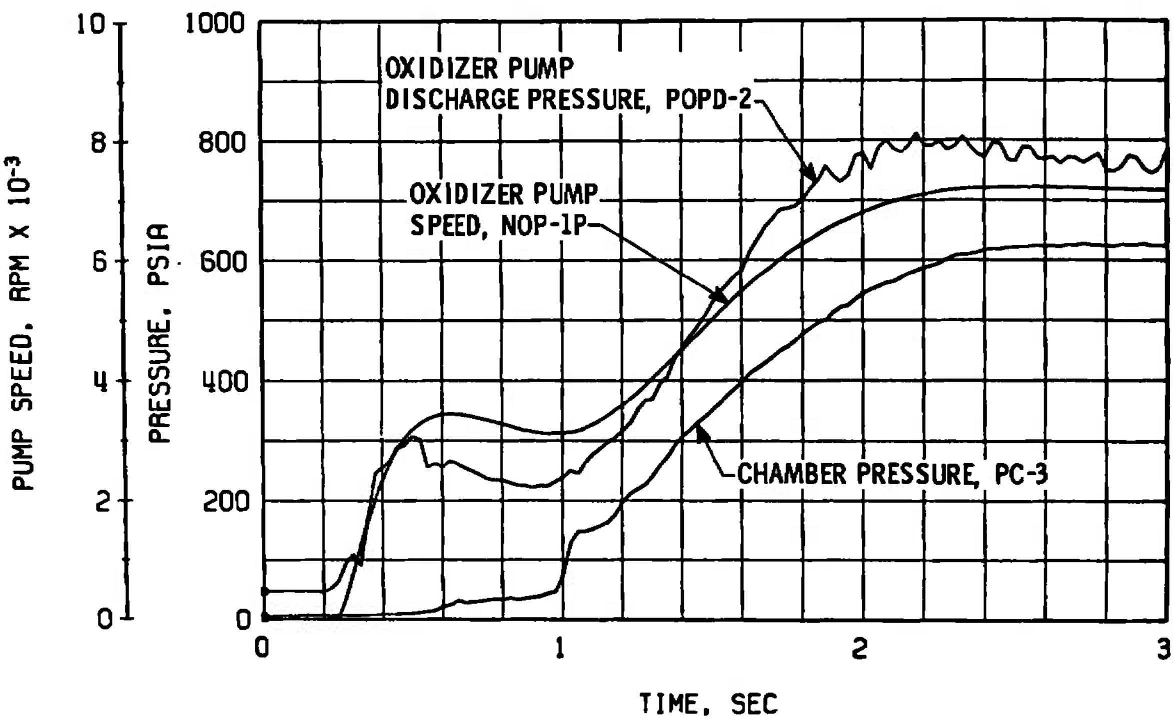


f. Thrust Chamber Throat, TTC-2

Fig. 33 Concluded

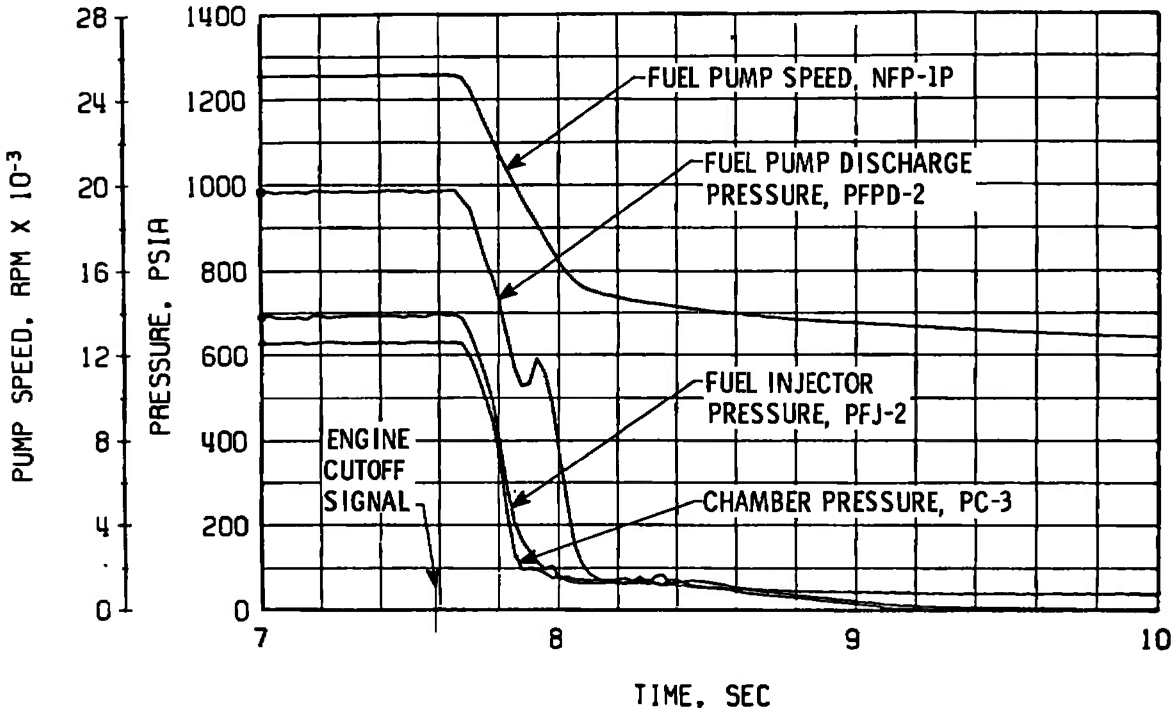


a. Thrust Chamber Fuel System, Start

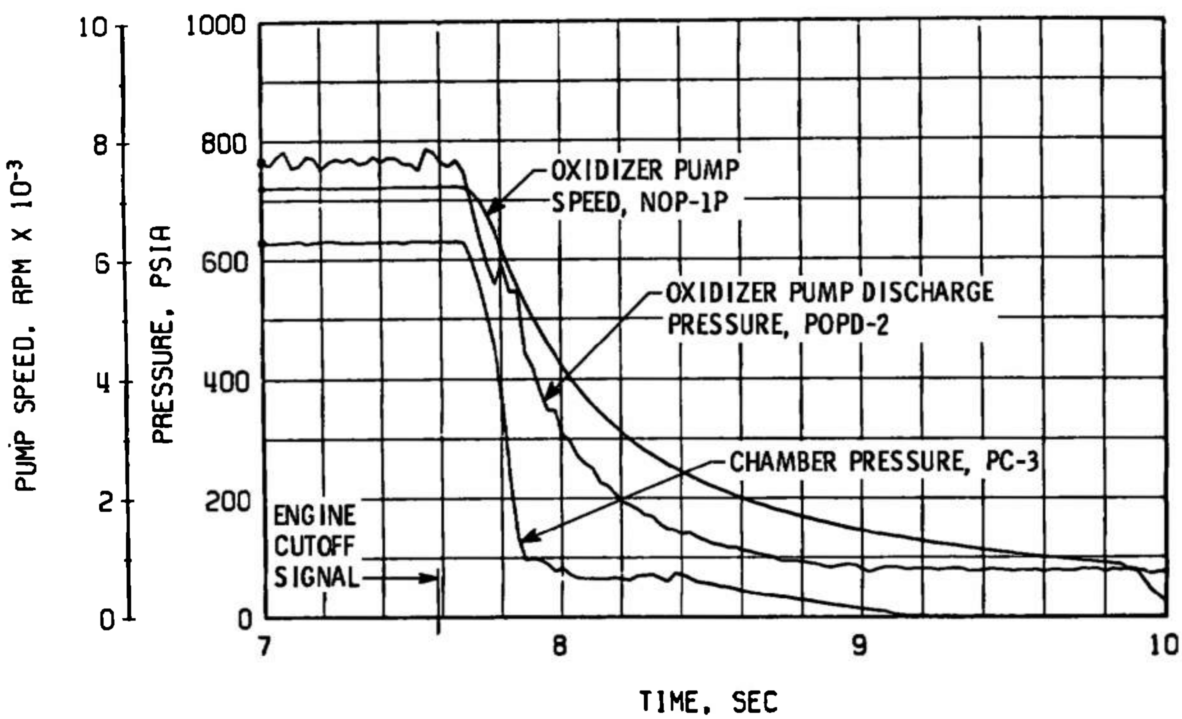


b. Thrust Chamber Oxidizer System, Start

Fig. 34 Engine Transient Operation, Firing 35B

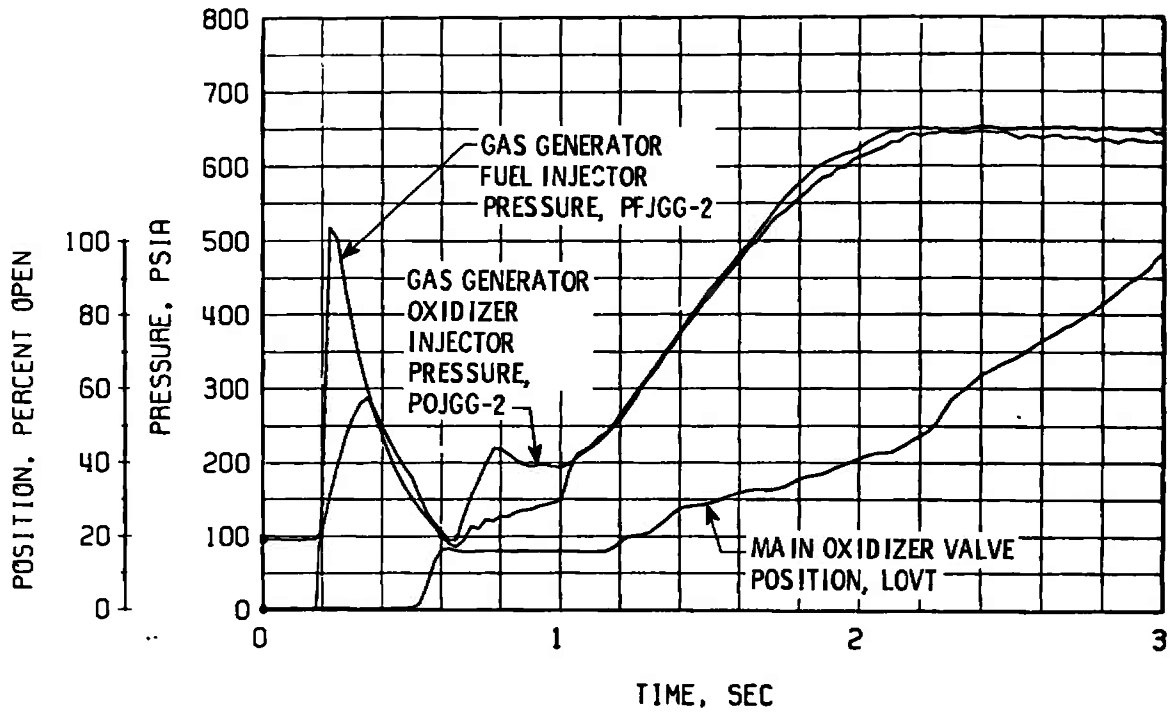


c. Thrust Chamber Fuel System, Shutdown

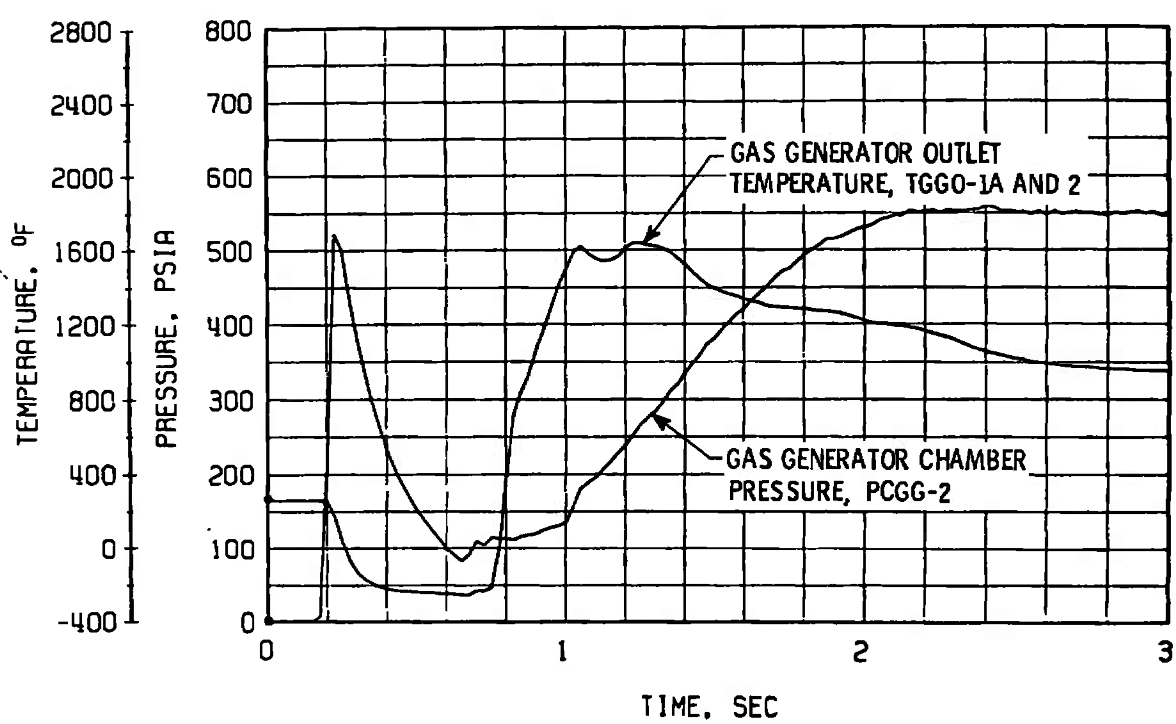


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 34 Continued

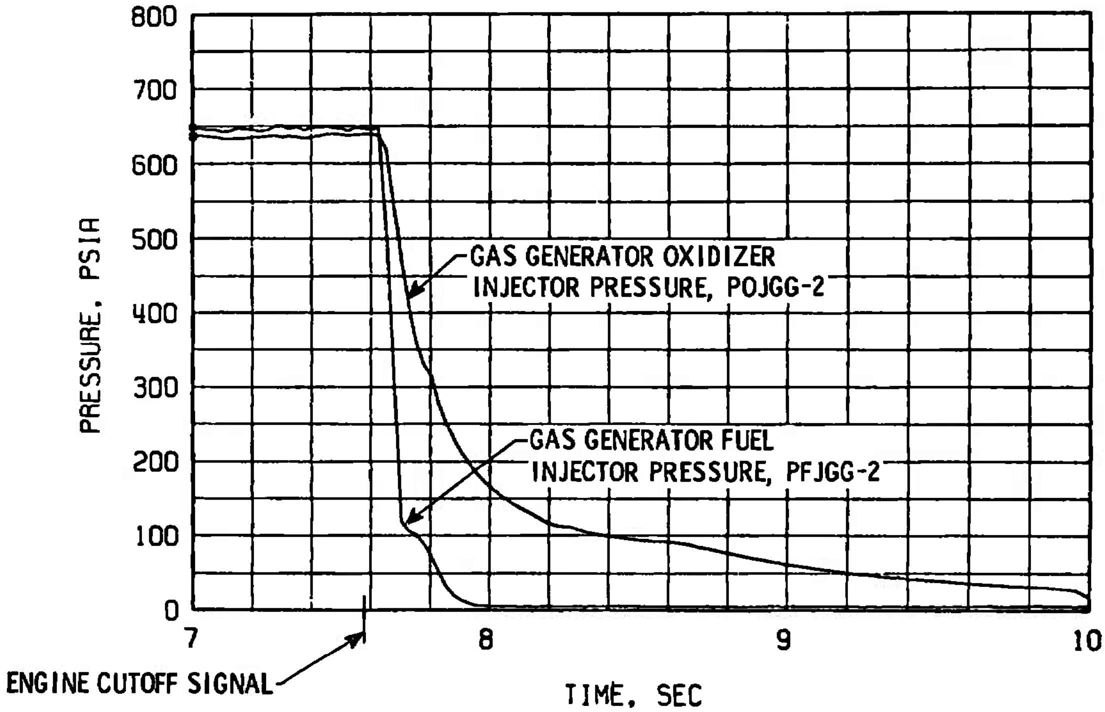


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

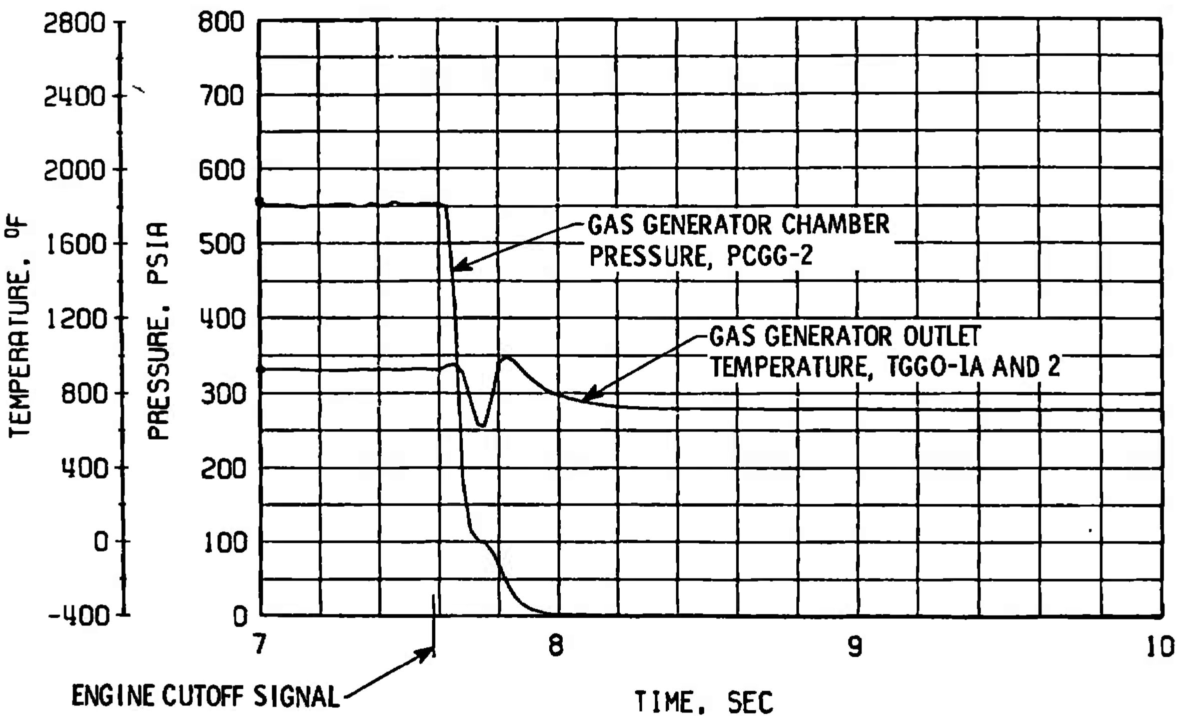


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 34 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 34 Concluded

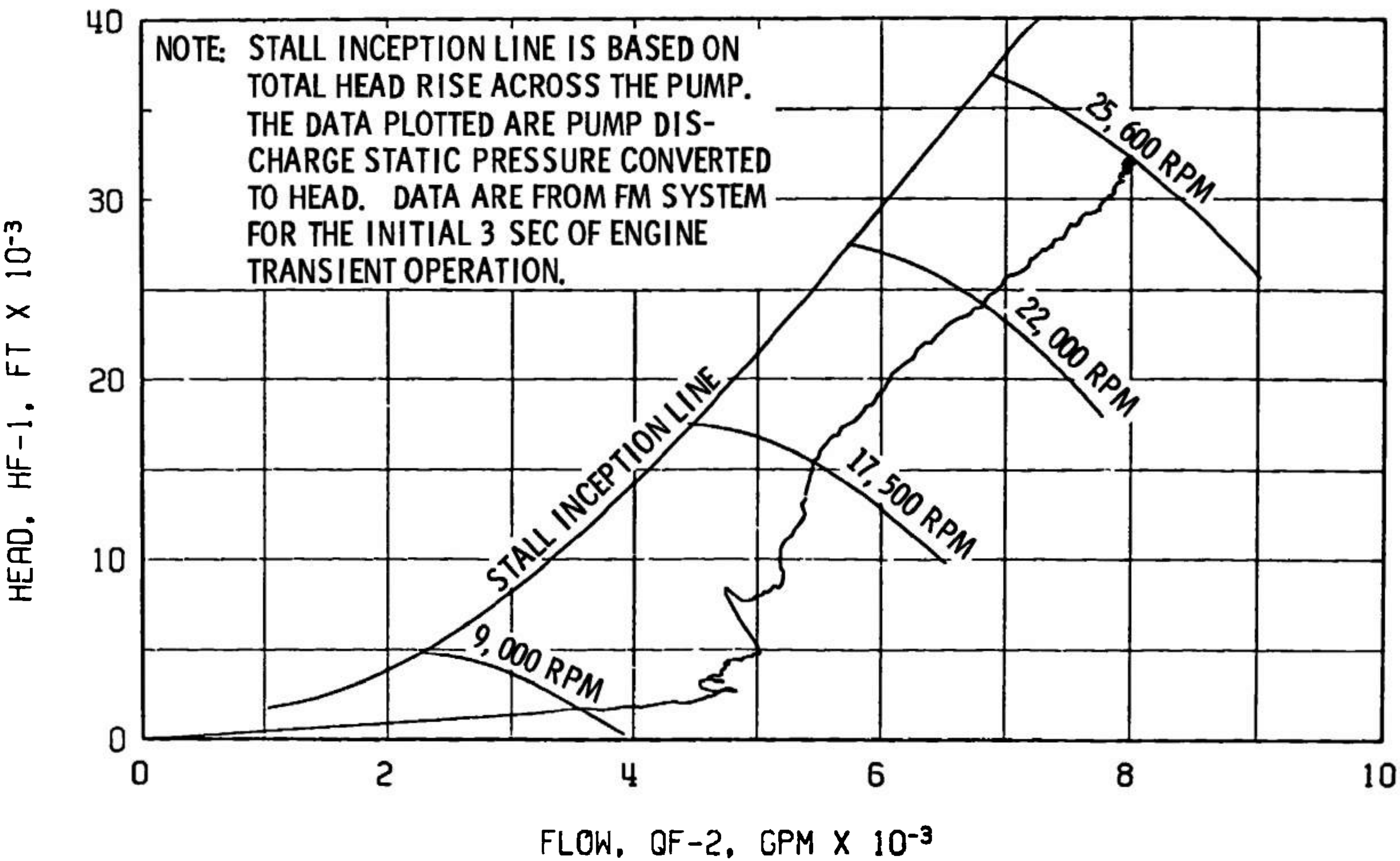


Fig. 35 Fuel Pump Start Transient Performance, Firing 35B

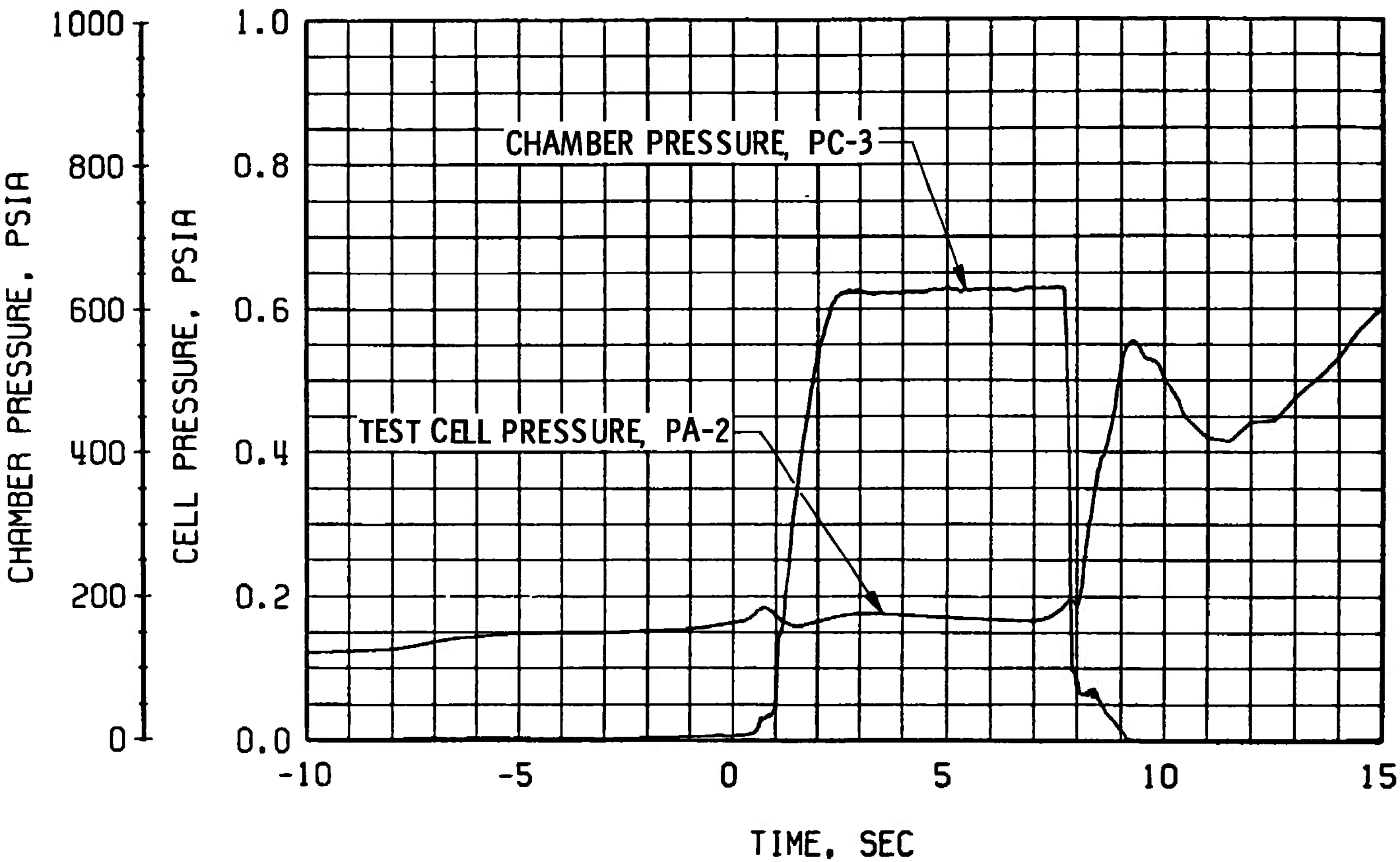
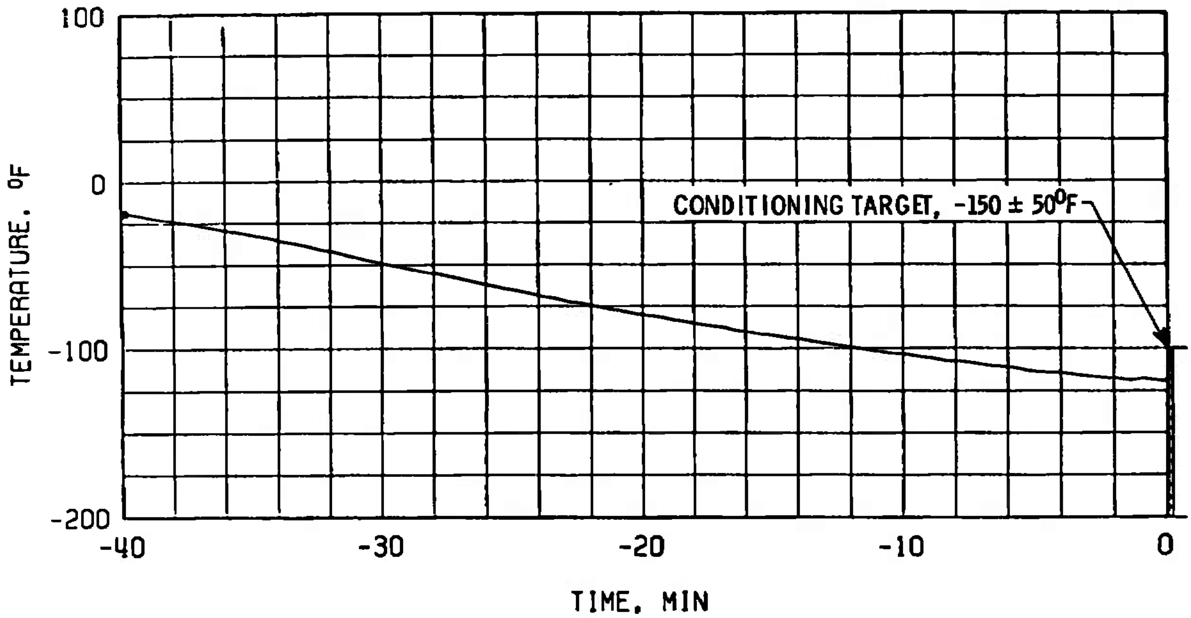
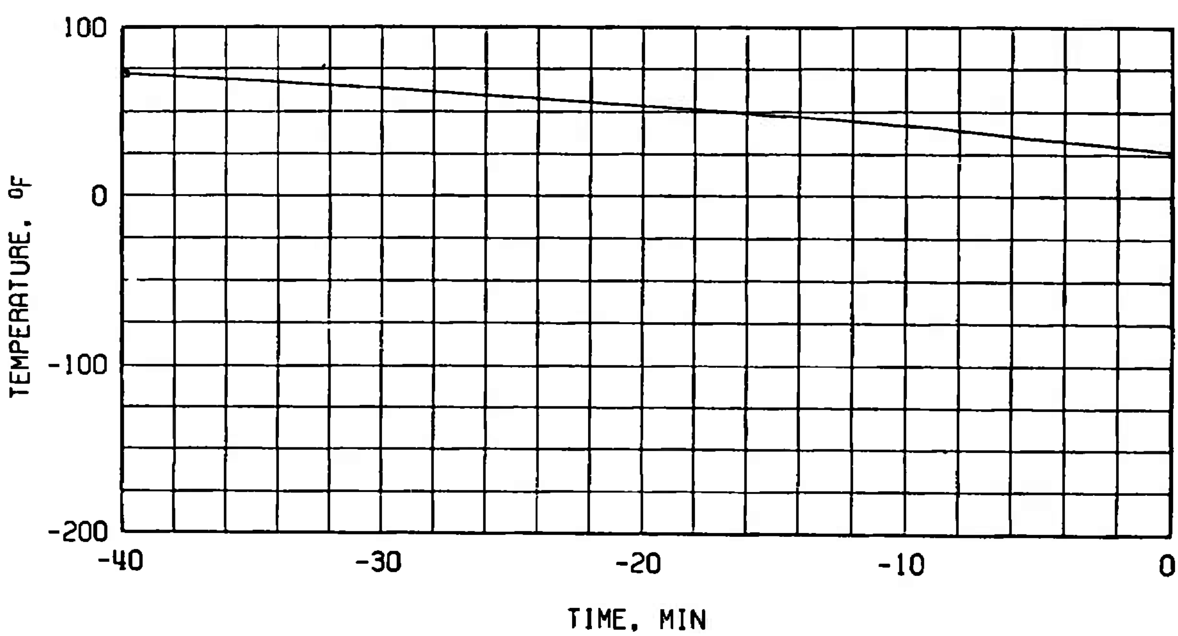


Fig. 36 Engine Ambient and Combustion Chamber Pressure, Firing 35B

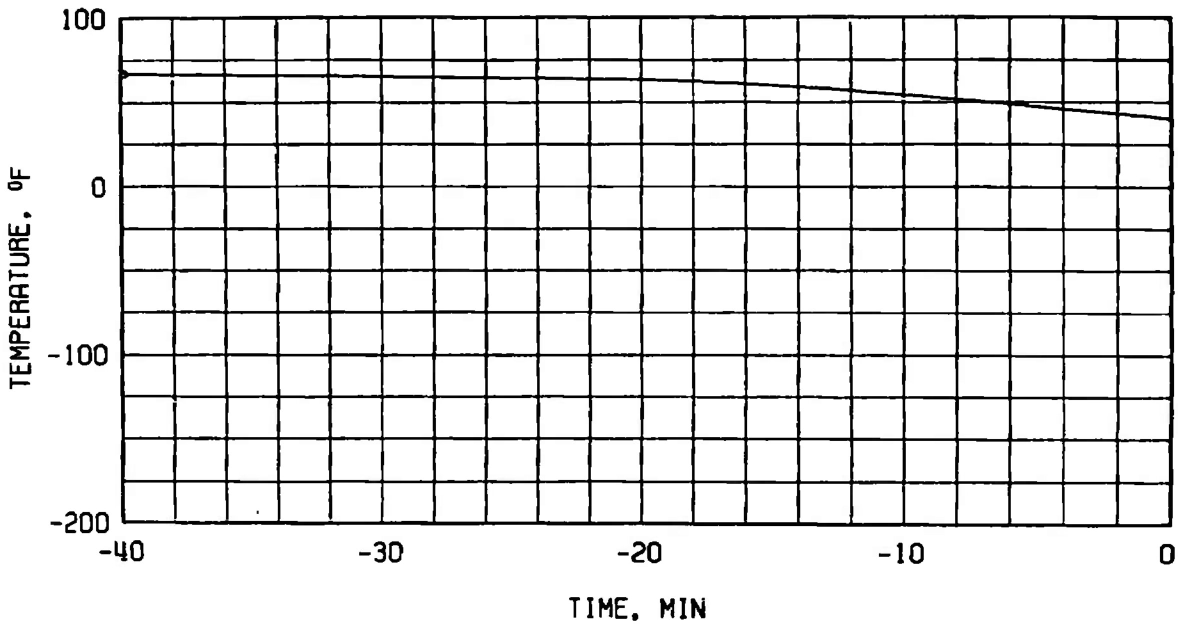


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

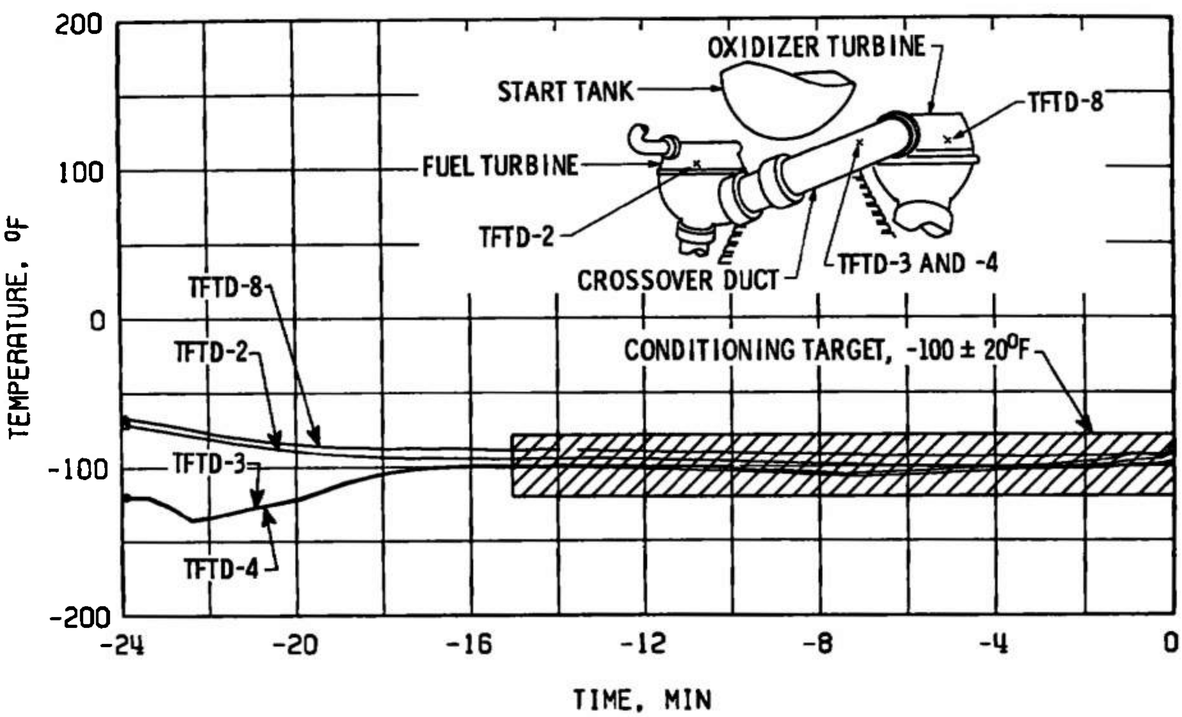


b. Gas Generator Body Temperature, TGGVRS

Fig. 37 Thermal Conditioning History of Engine Components, Firing 36A

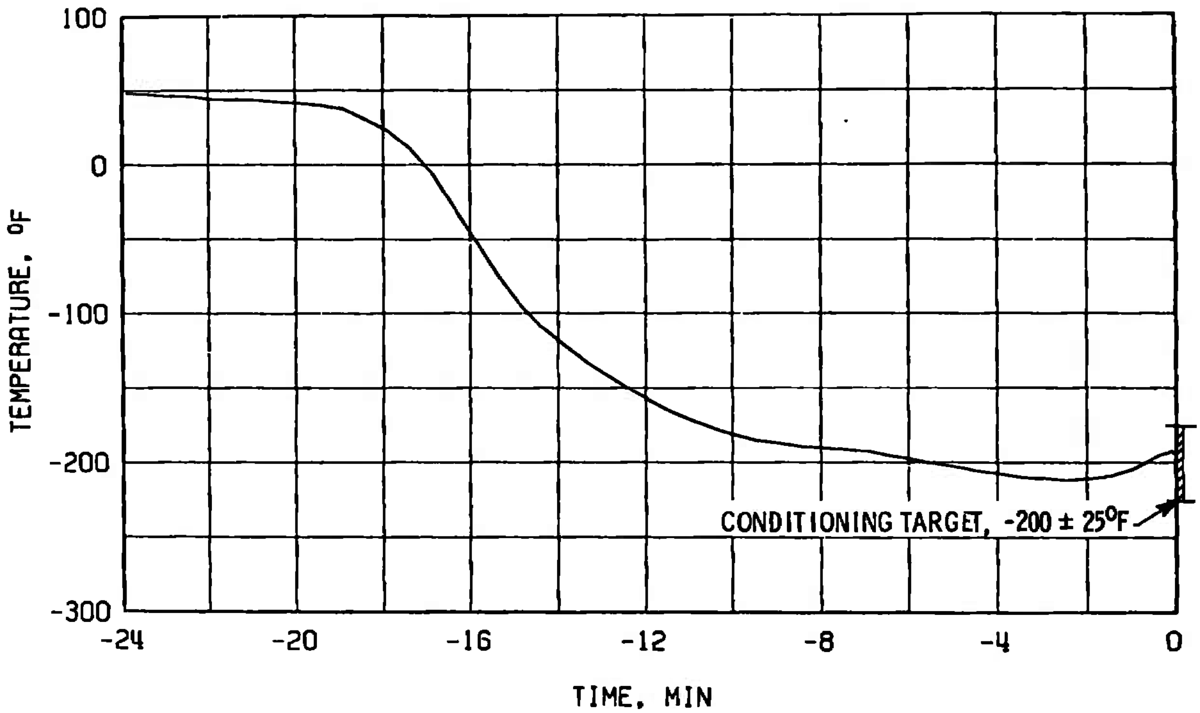


c. Start Tank Discharge Valve Opening Control Temperature, TSTDVOC

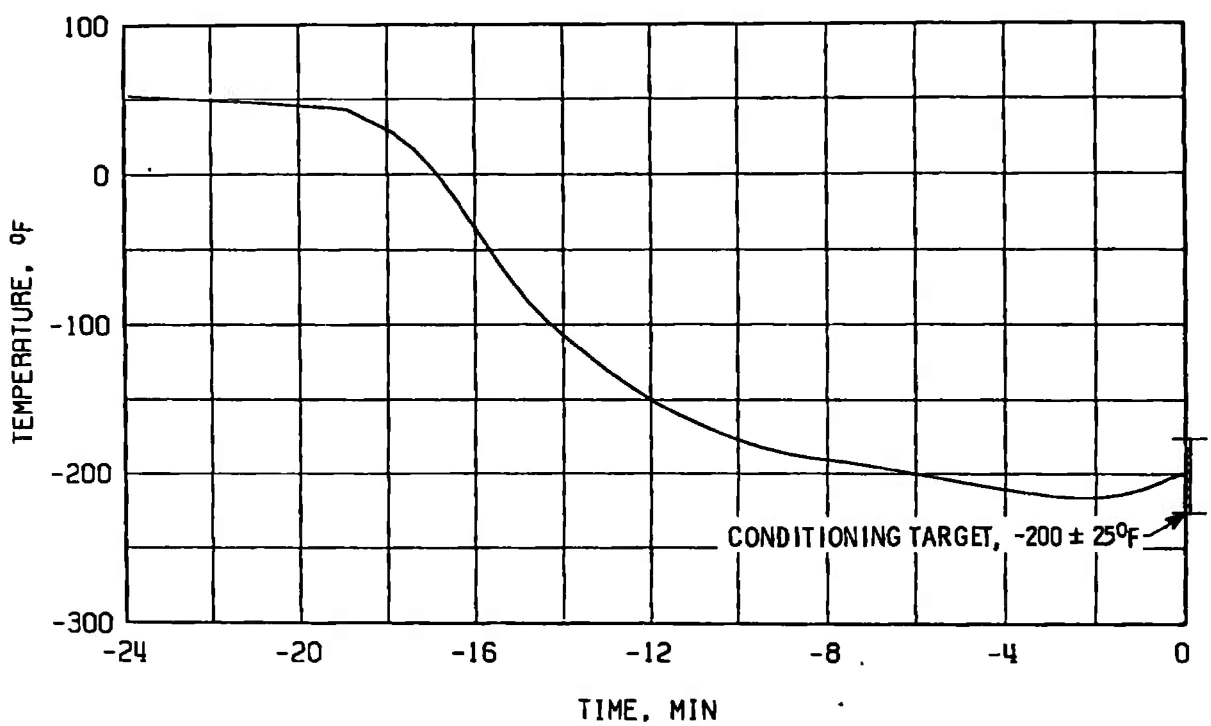


d. Crossover Duct, TFTD

Fig. 37 Continued

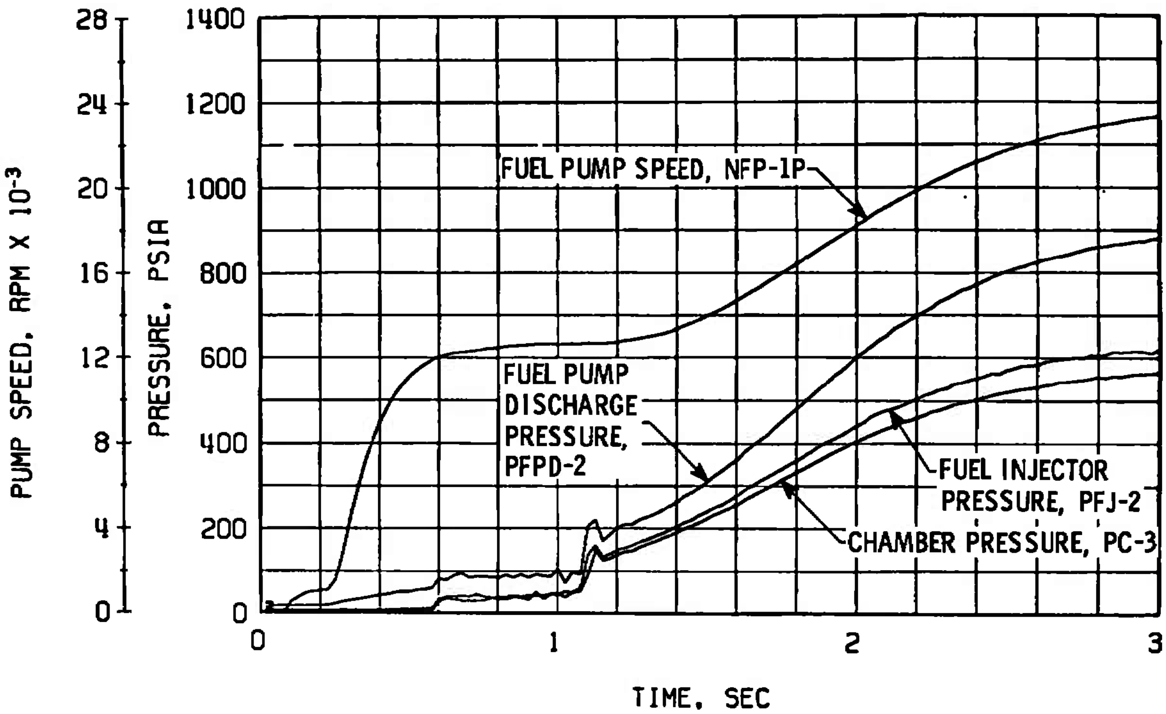


e. Thrust Chamber Throat, TTC-1P

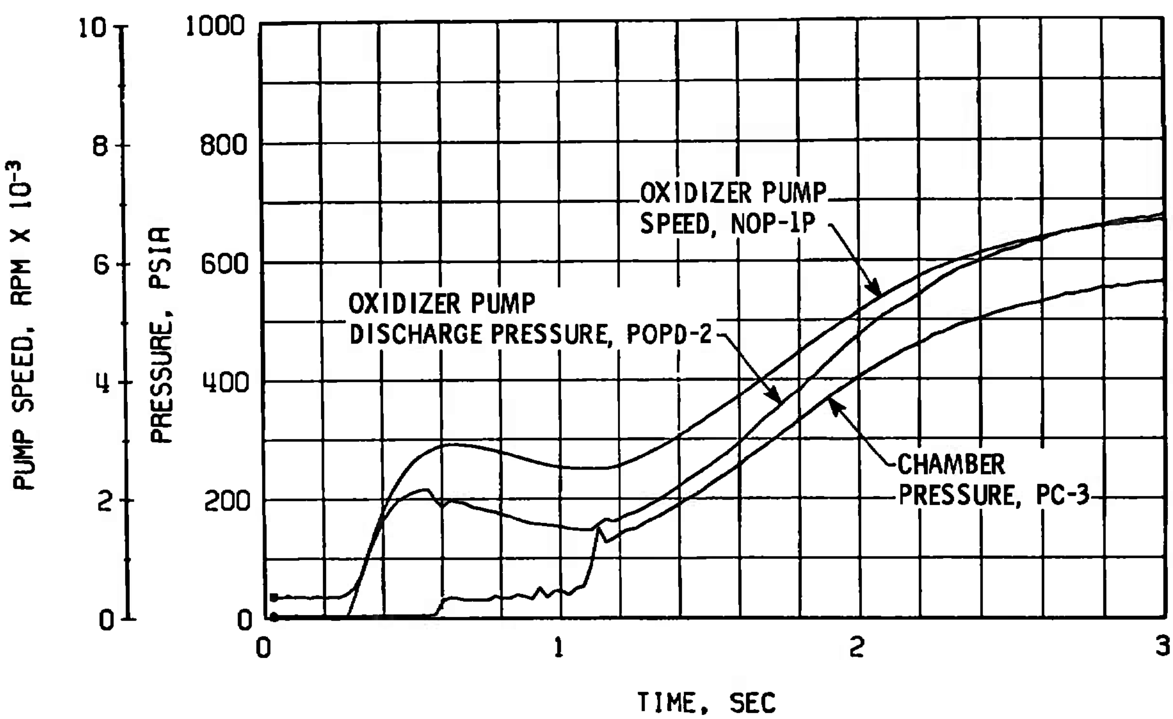


f. Thrust Chamber Throat, TTC-2

Fig. 37 Concluded

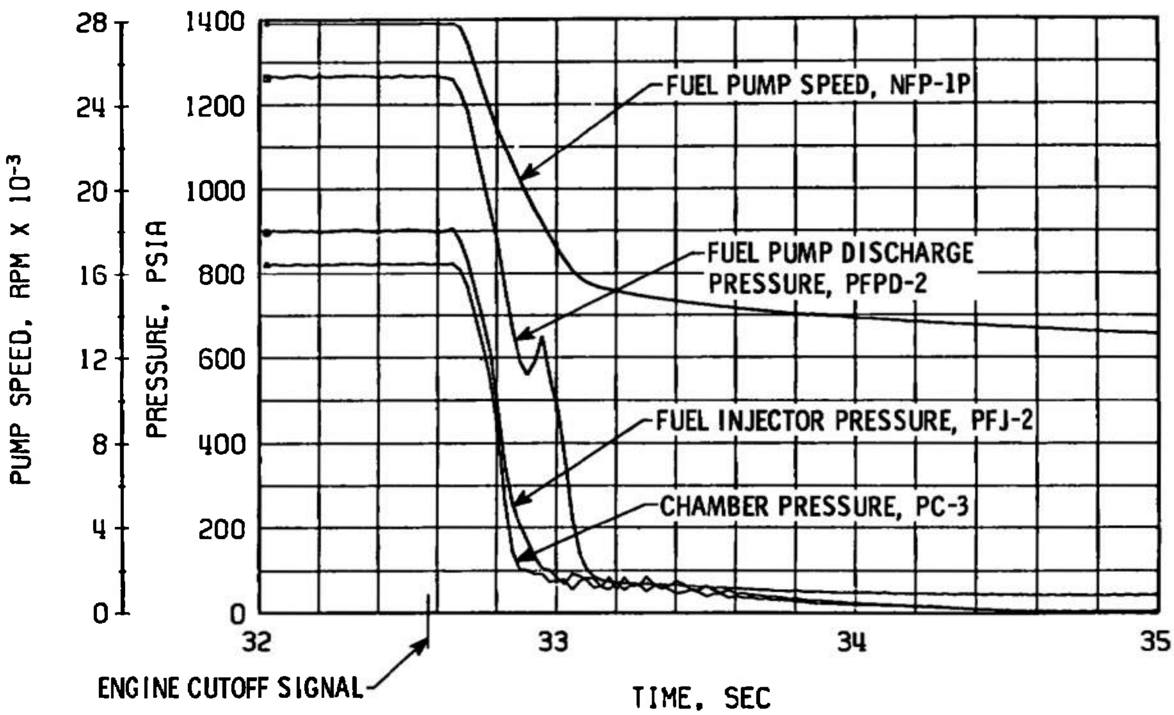


a. Thrust Chamber Fuel System, Start

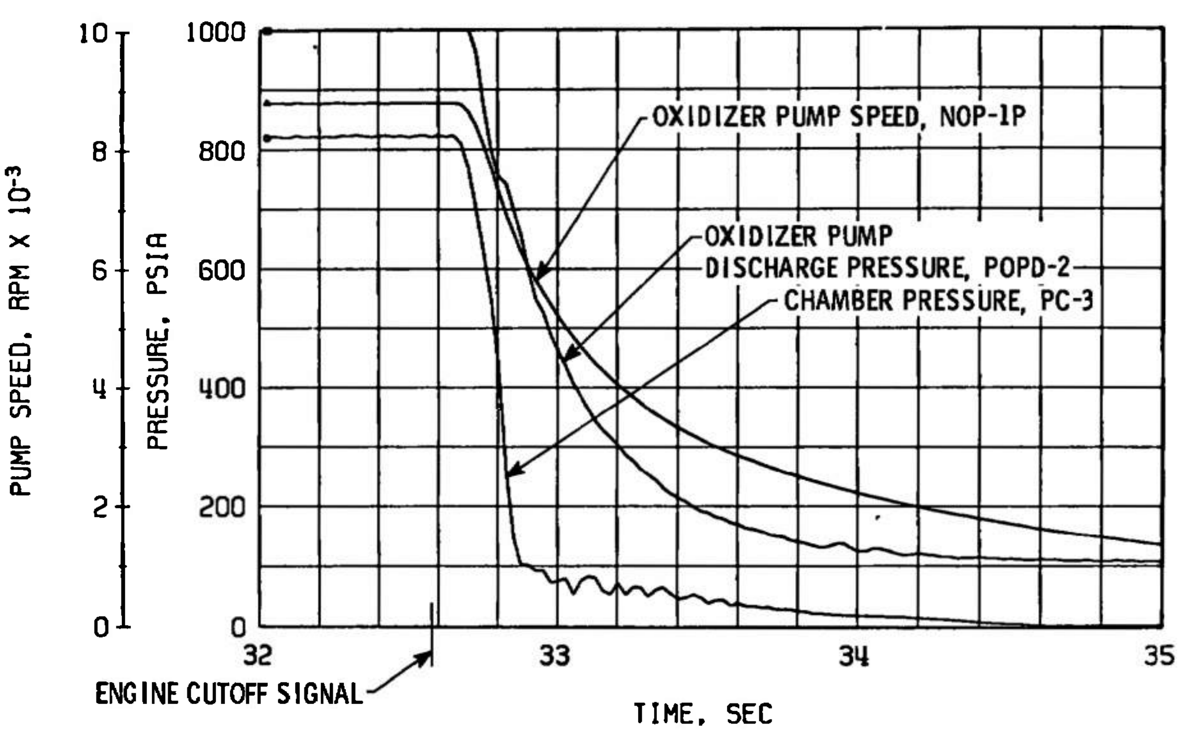


b. Thrust Chamber Oxidizer System, Start

Fig. 38 Engine Transient Operation, Firing 36A

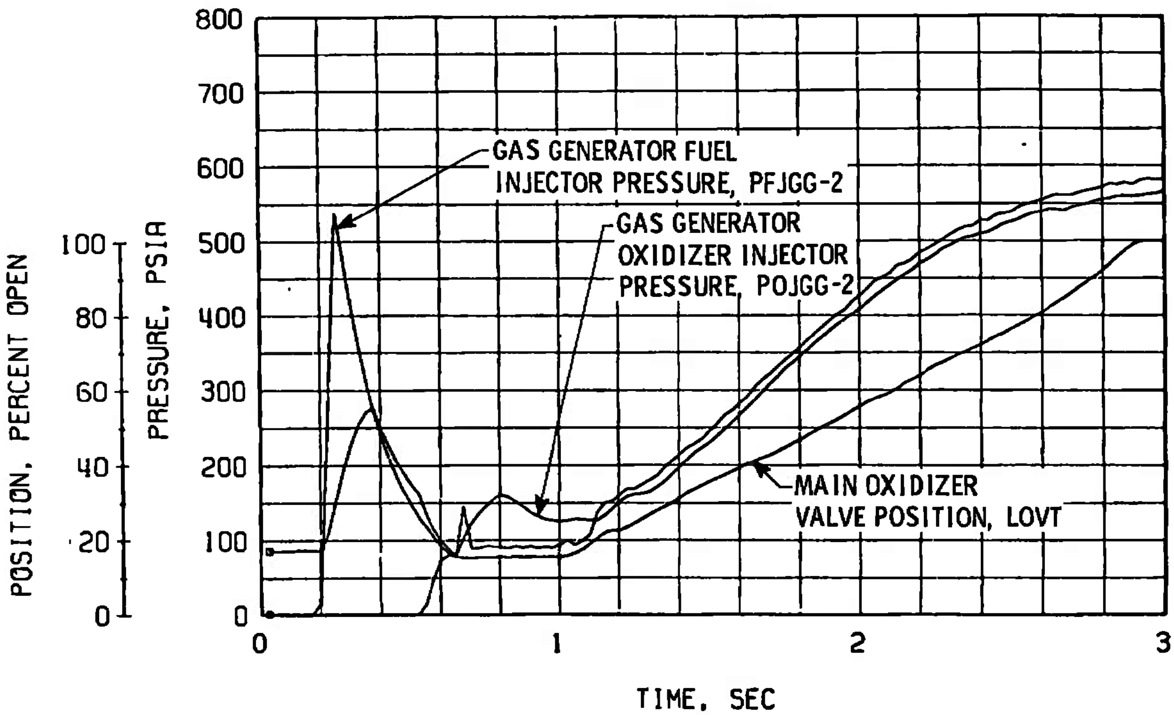


c. Thrust Chamber Fuel System, Shutdown

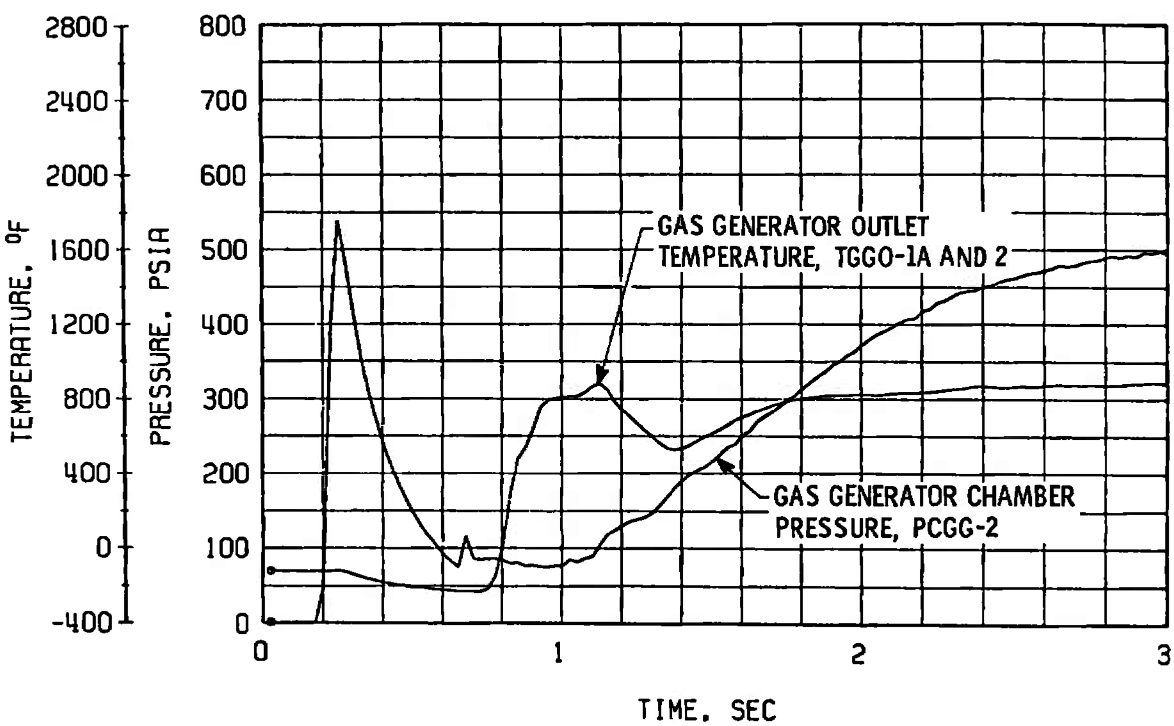


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 38 Continued

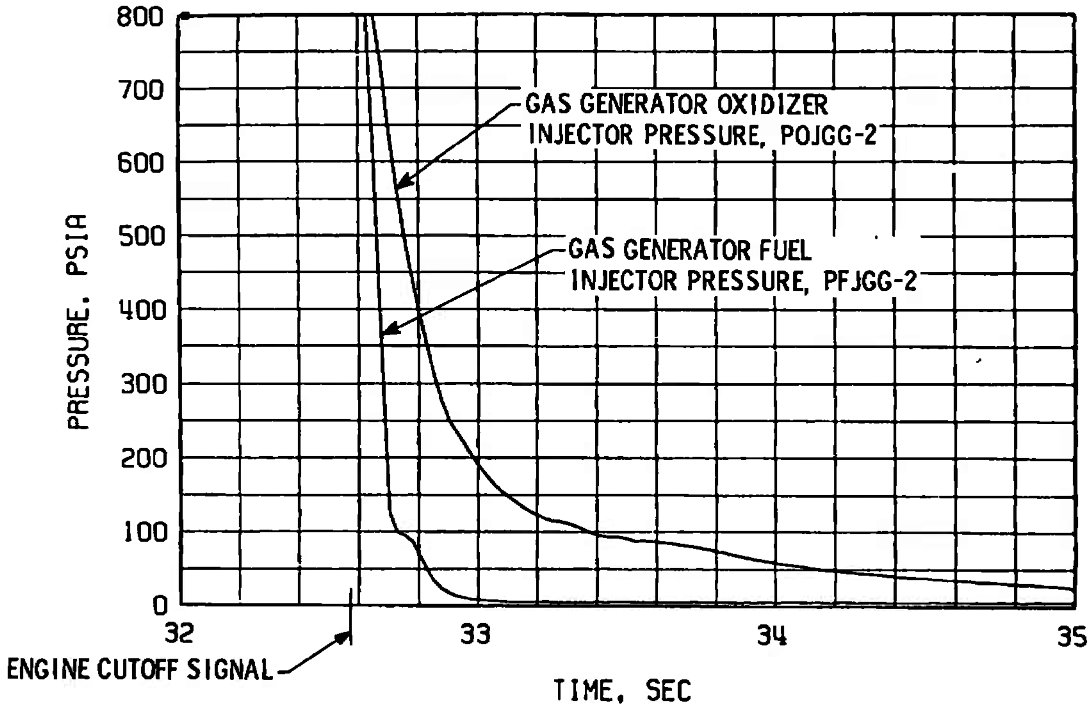


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

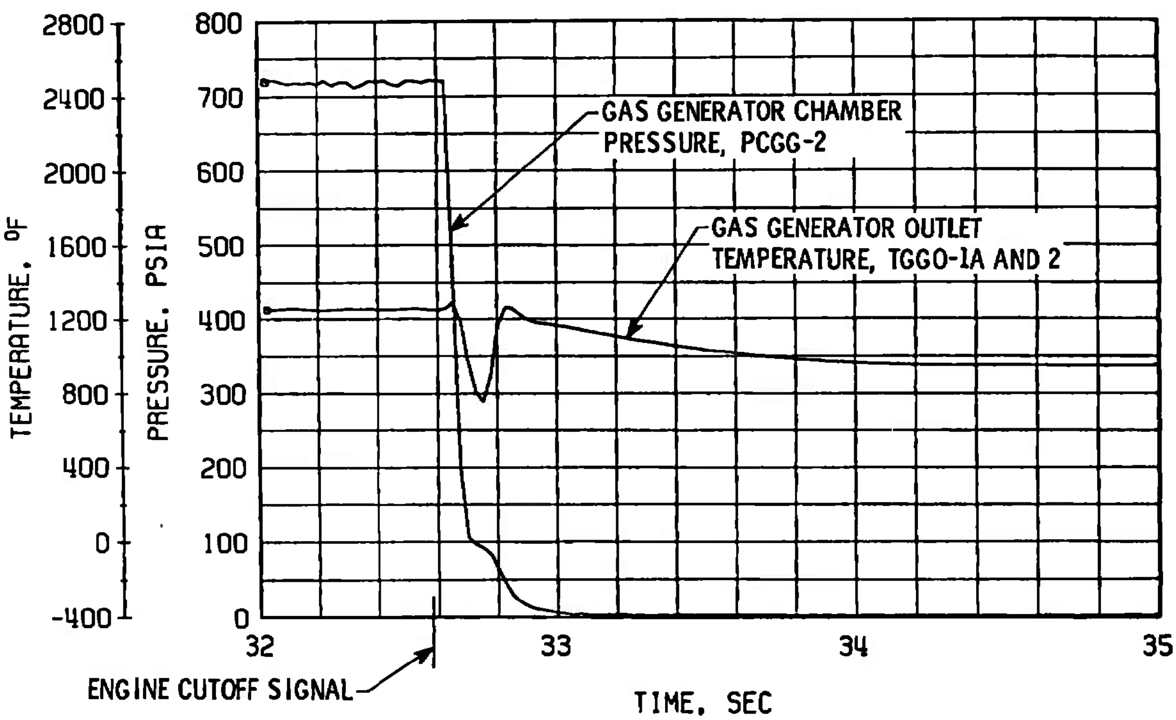


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 38 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 38 Concluded

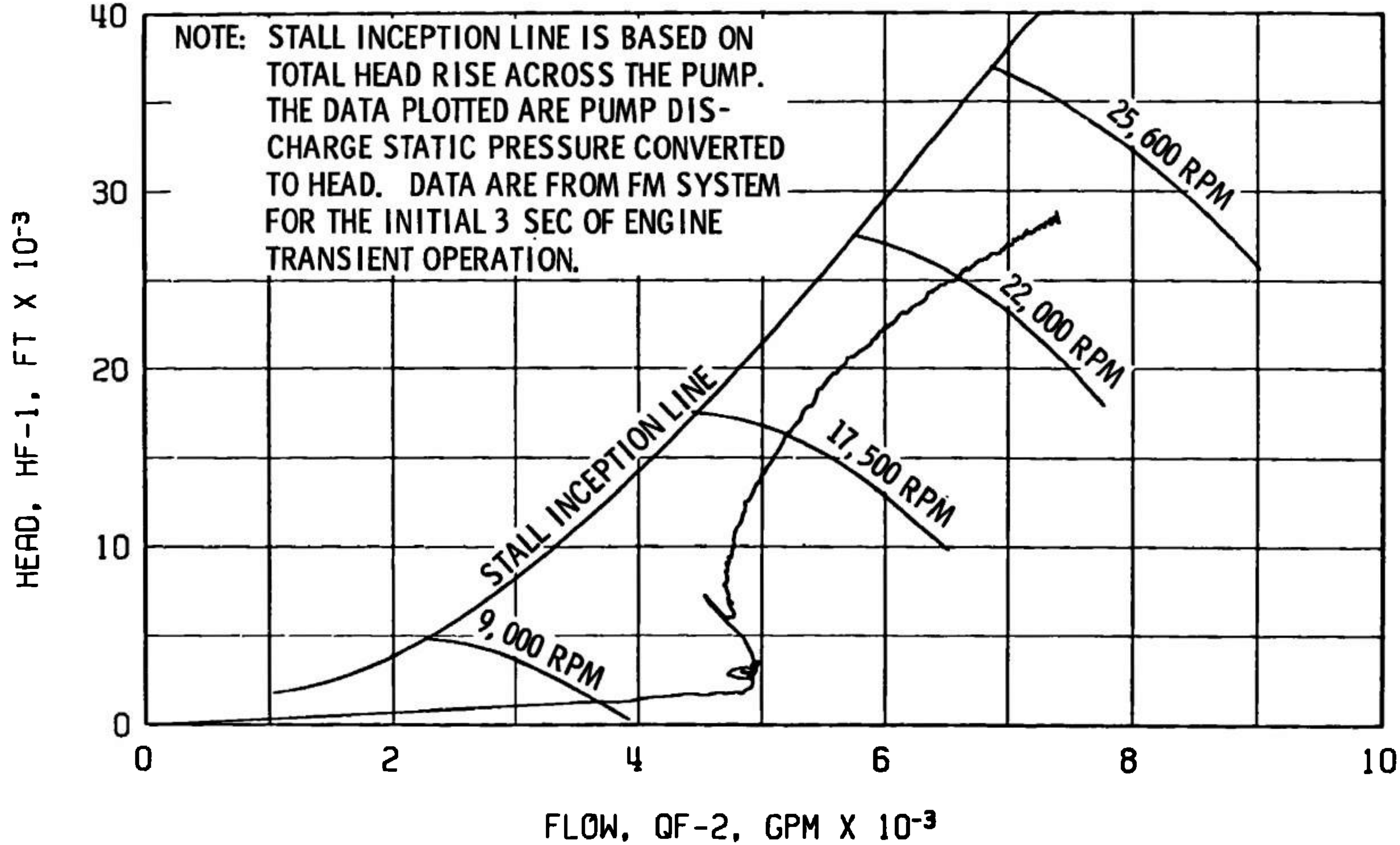


Fig. 39 Fuel Pump Start Transient Performance, Firing 36A

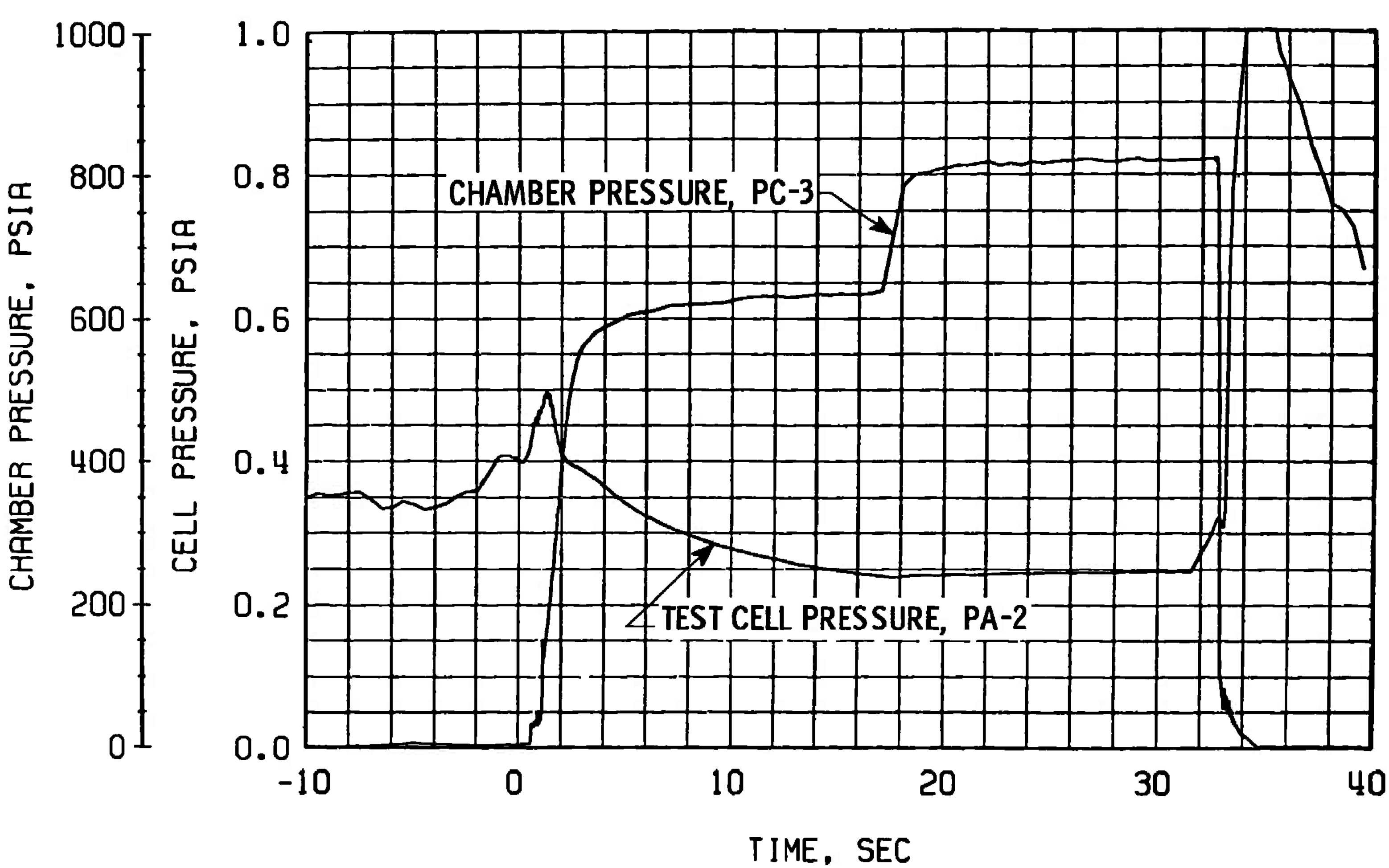
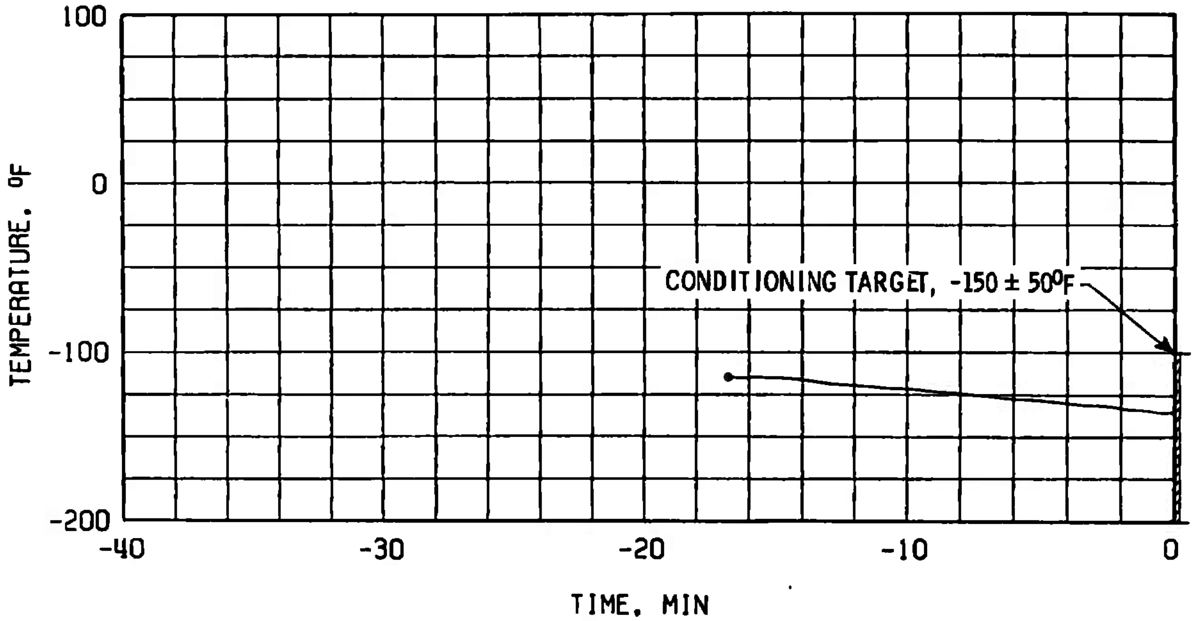
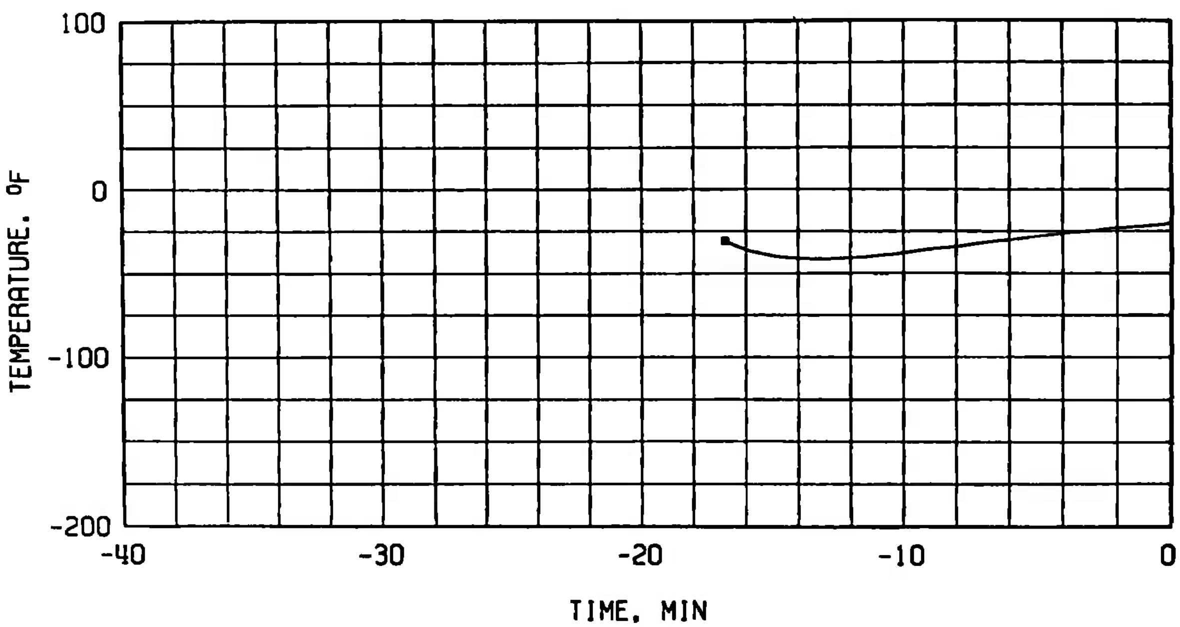


Fig. 40 Engine Ambient and Combustion Chamber Pressure, Firing 36A

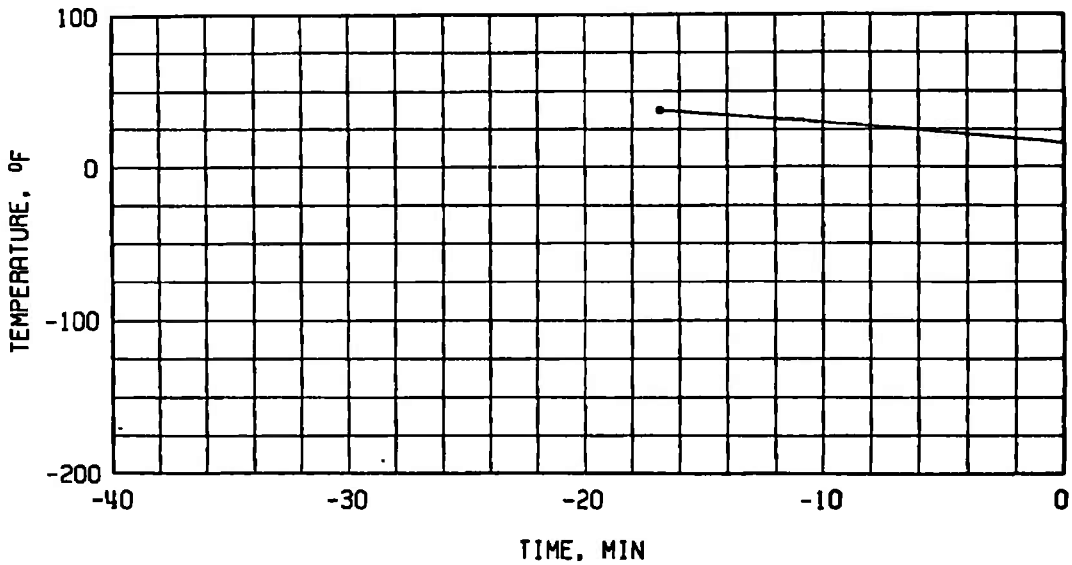


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

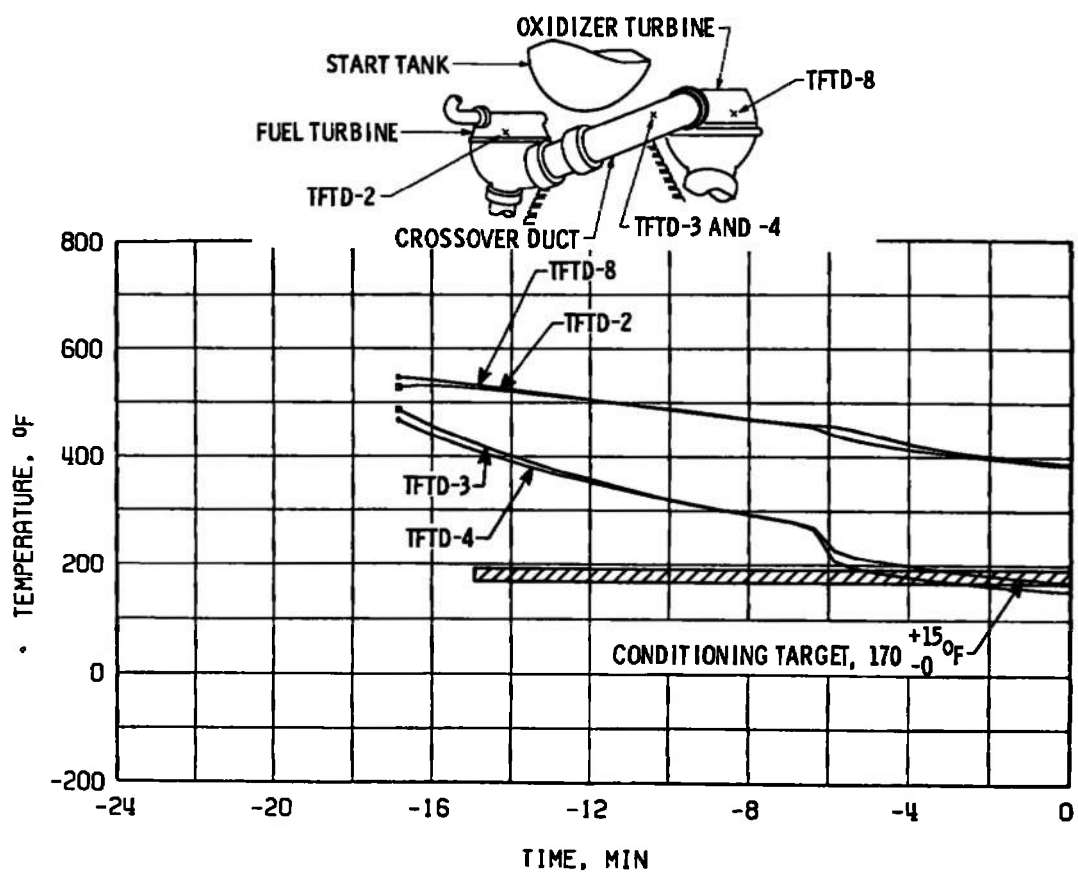


b. Gas Generator Body Temperature, TGGVRS

Fig. 41 Thermal Conditioning History of Engine Components, Firing 36B

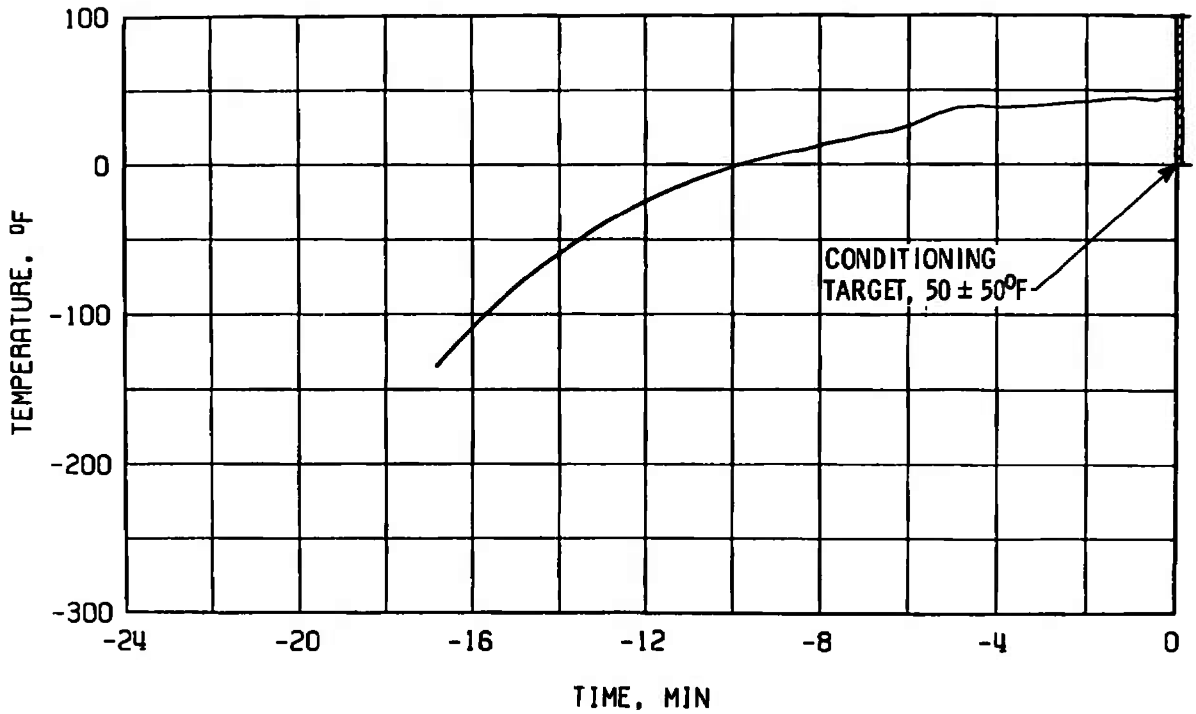


c. Start Tank Discharge Valve Opening Control Temperature, TSTDVOC

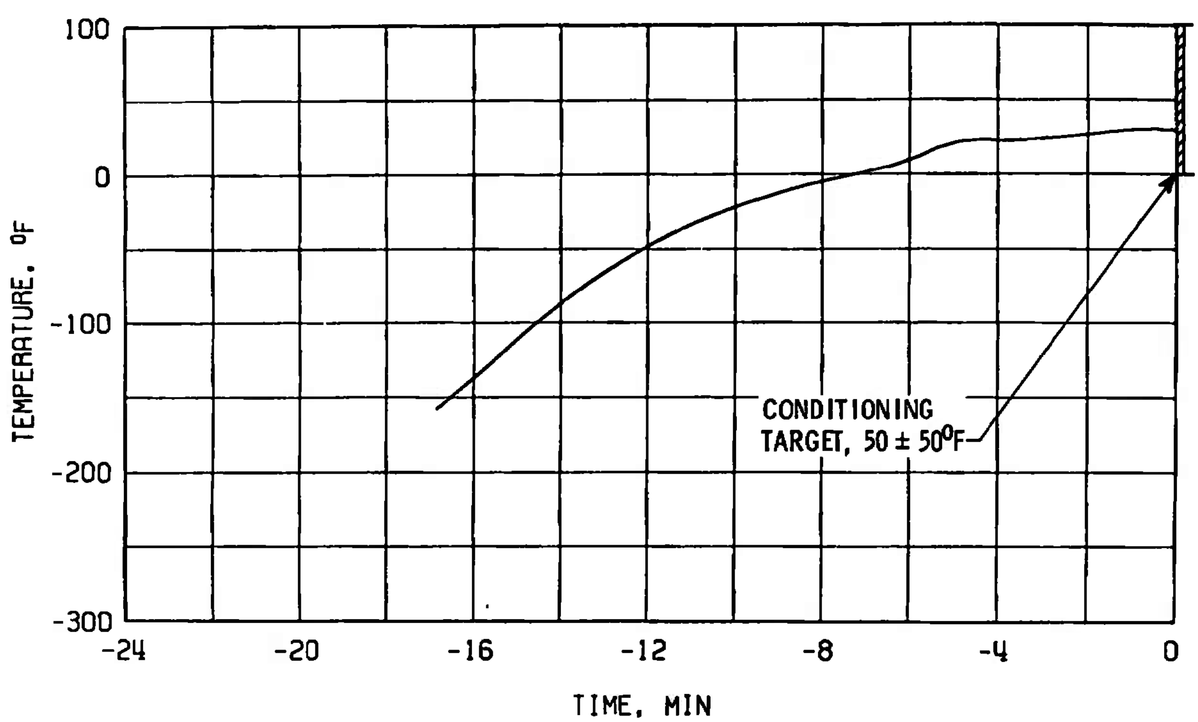


d. Crossover Duct, TFTD

Fig. 41 Continued

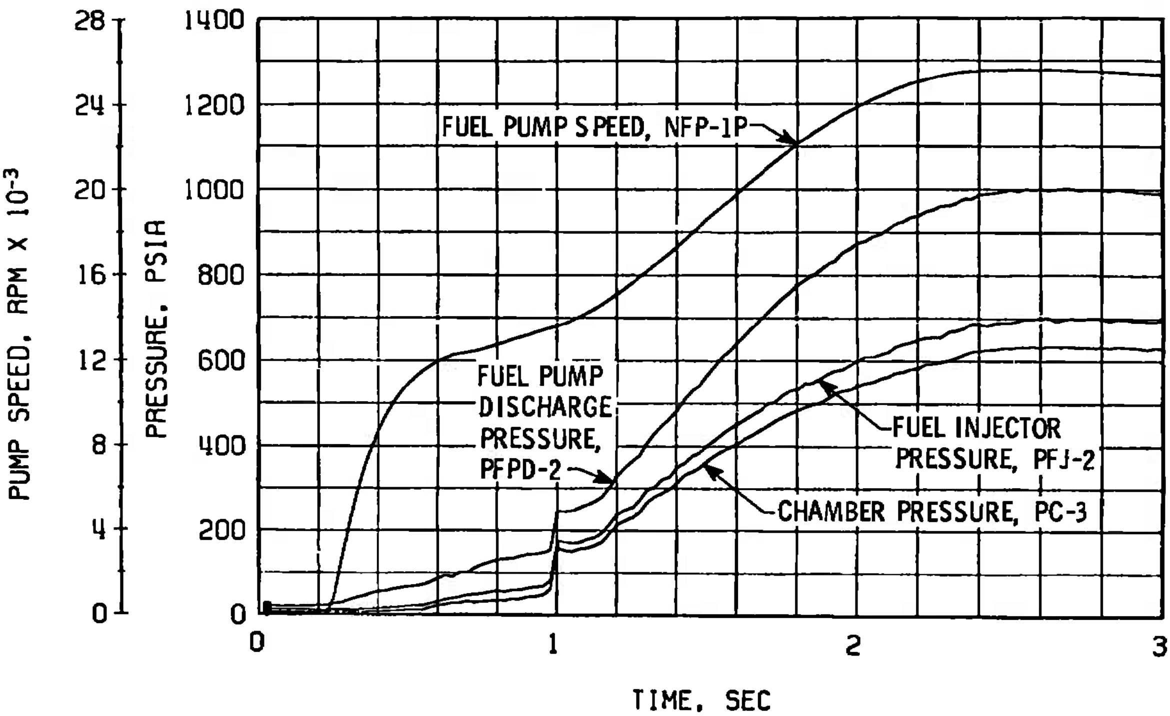


e. Thrust Chamber Throat, TTC-1P

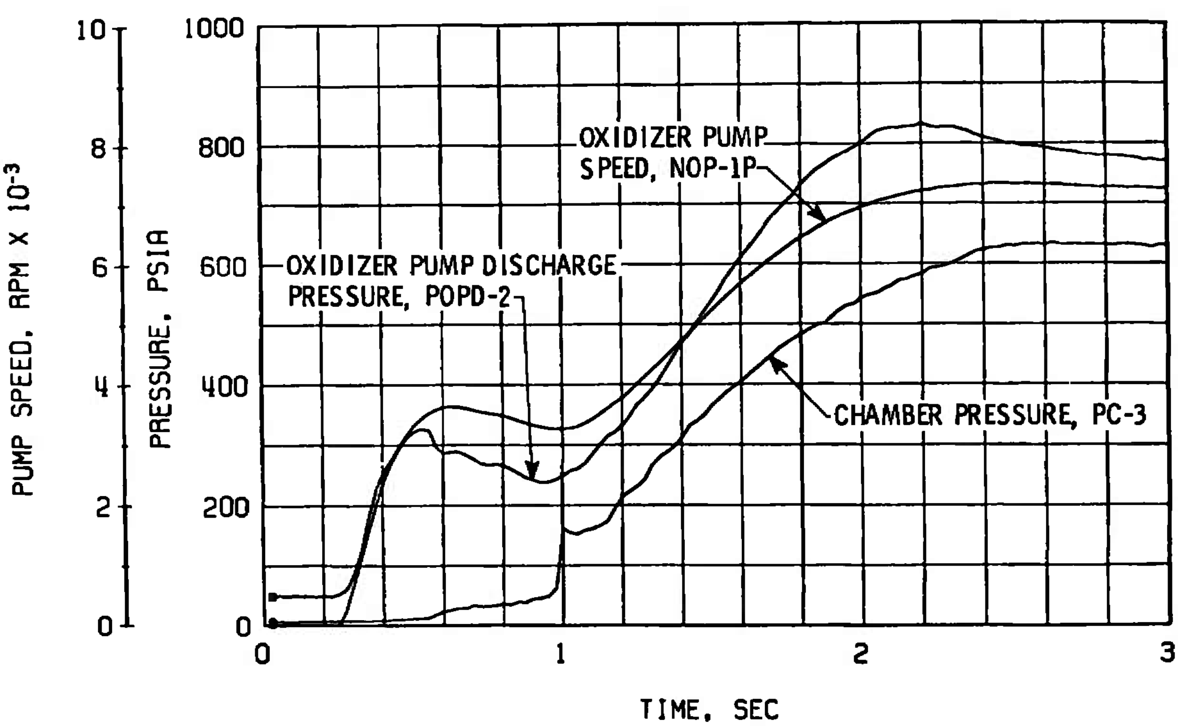


f. Thrust Chamber Throat, TTC-2

Fig. 41 Concluded

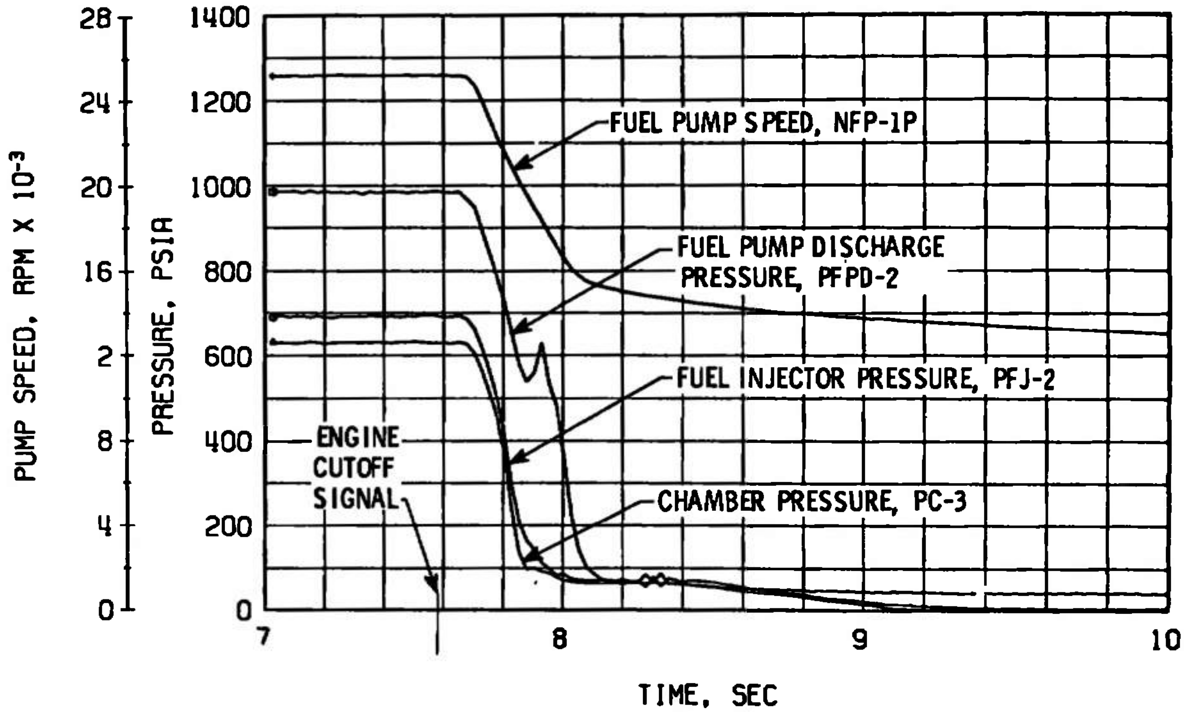


a. Thrust Chamber Fuel System, Start

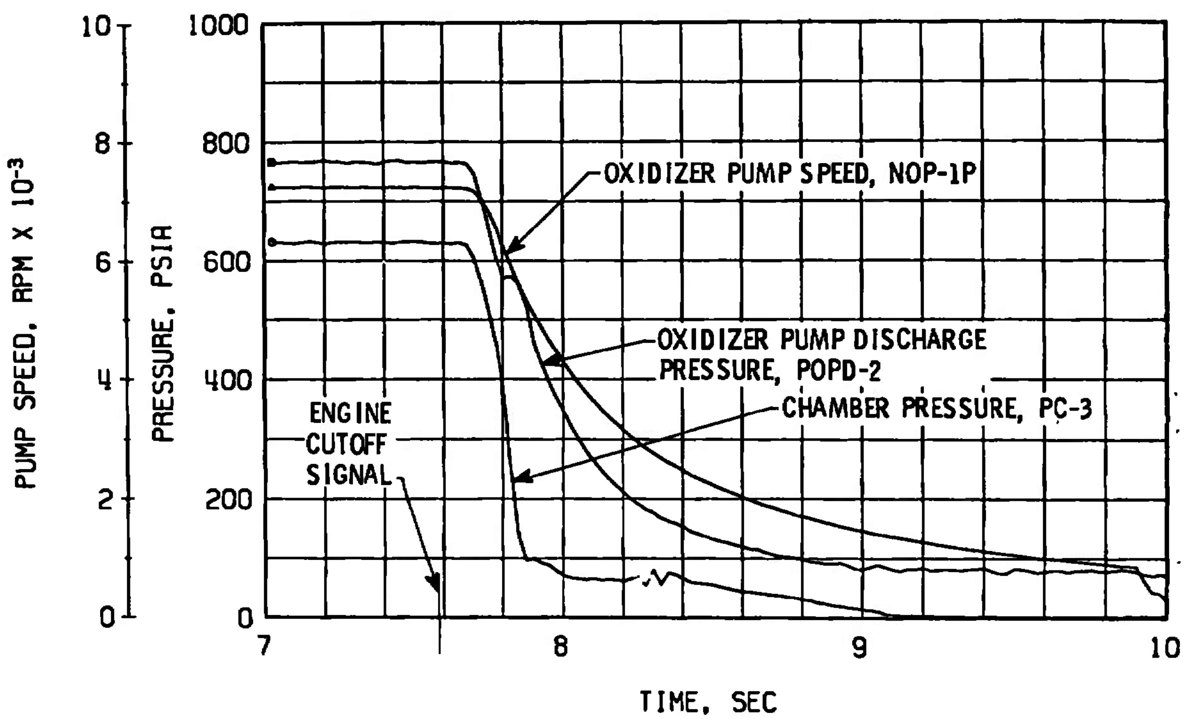


b. Thrust Chamber Oxidizer System, Start

Fig. 42 Engine Transient Operation, Firing 36B

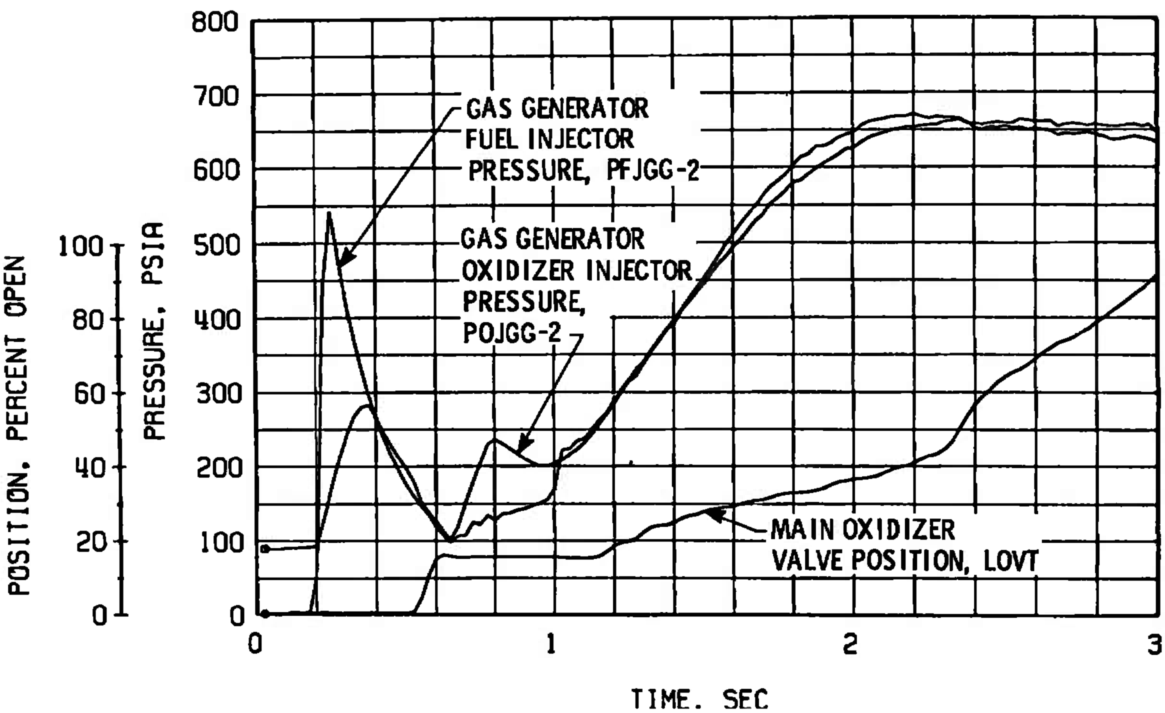


c. Thrust Chamber Fuel System, Shutdown

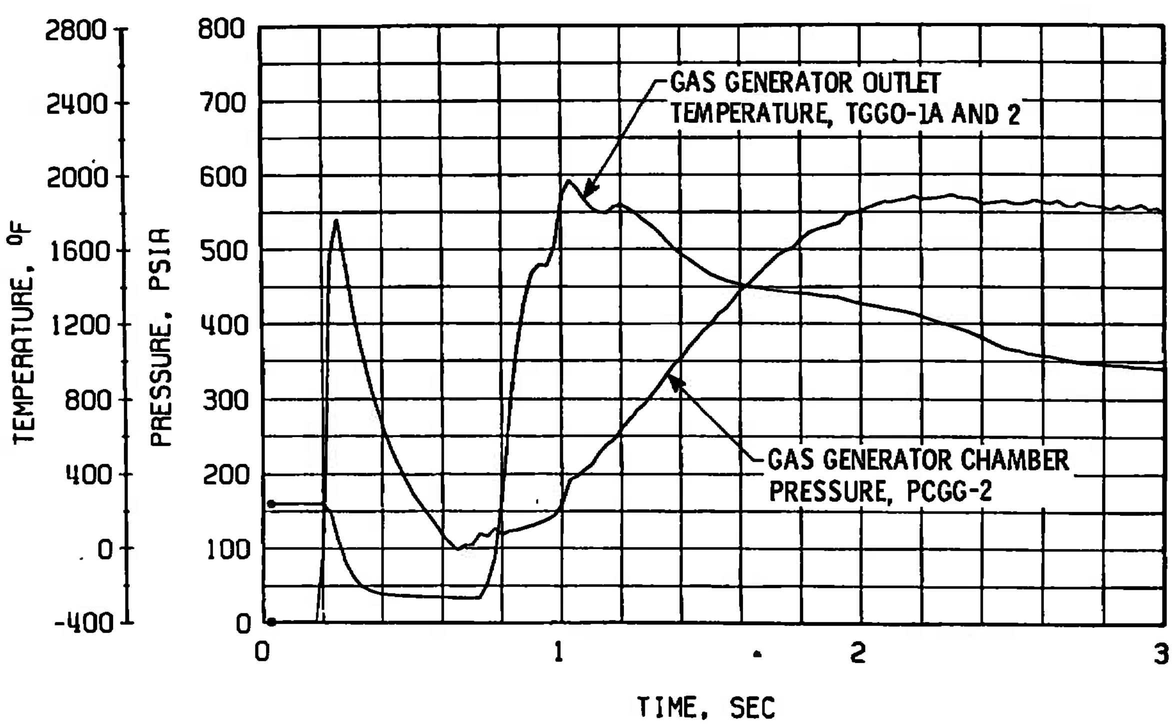


d. Thrust Chomber Oxidizer System, Shutdown

Fig. 42 Continued

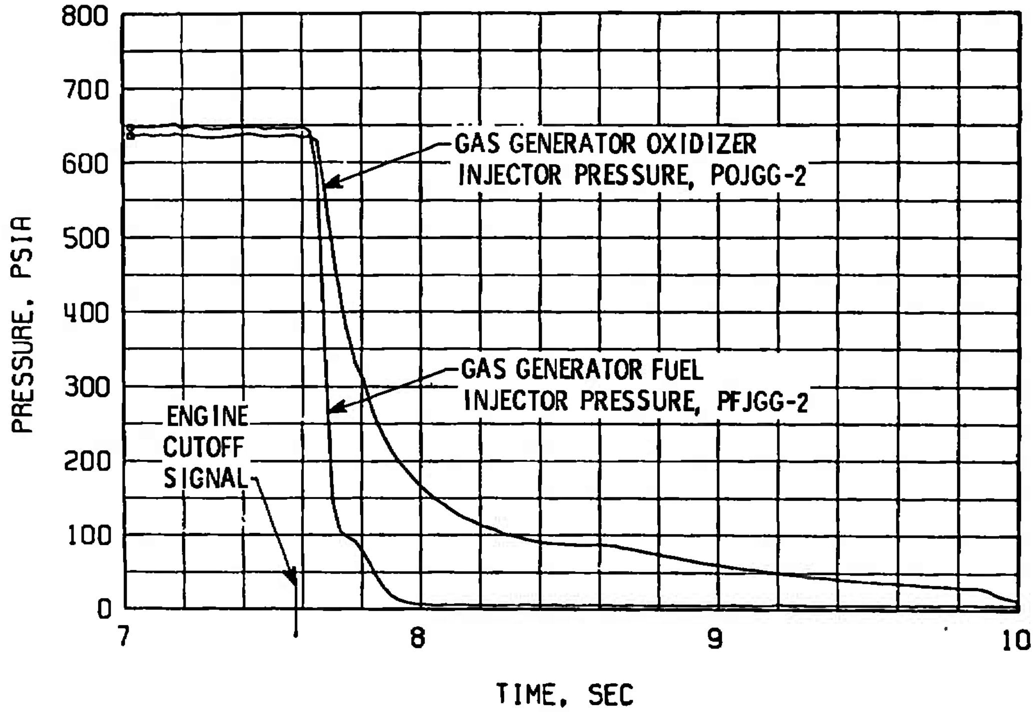


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

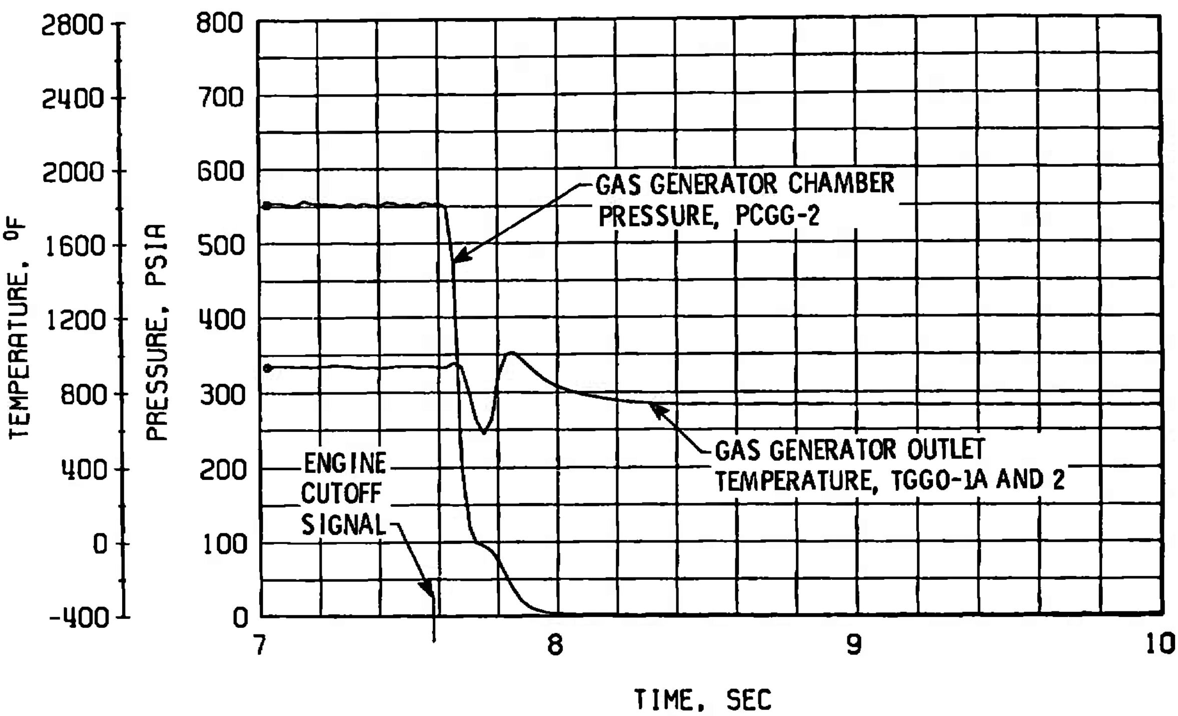


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 42 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 42 Concluded

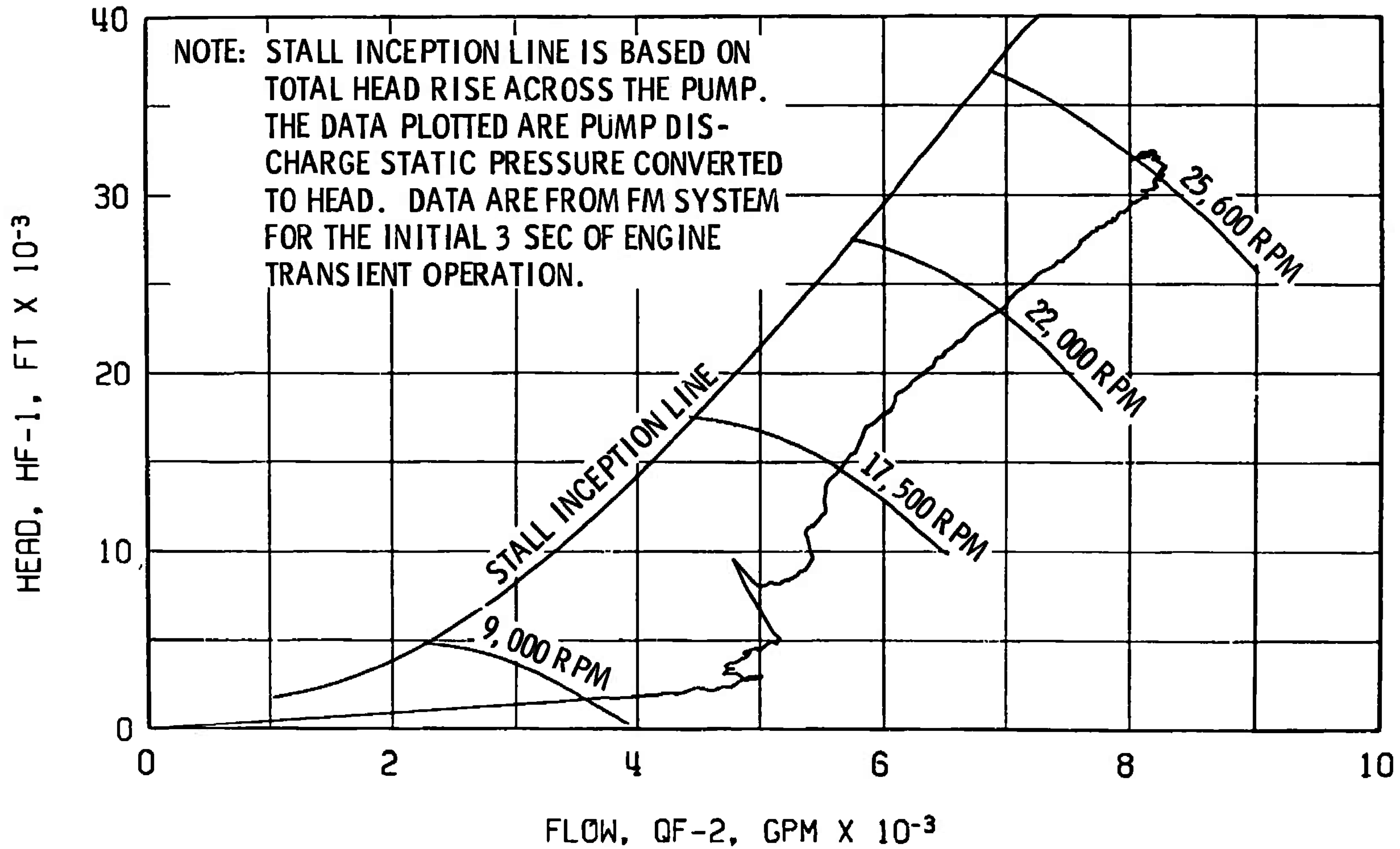


Fig. 43 Fuel Pump Start Transient Performance, Firing 36B

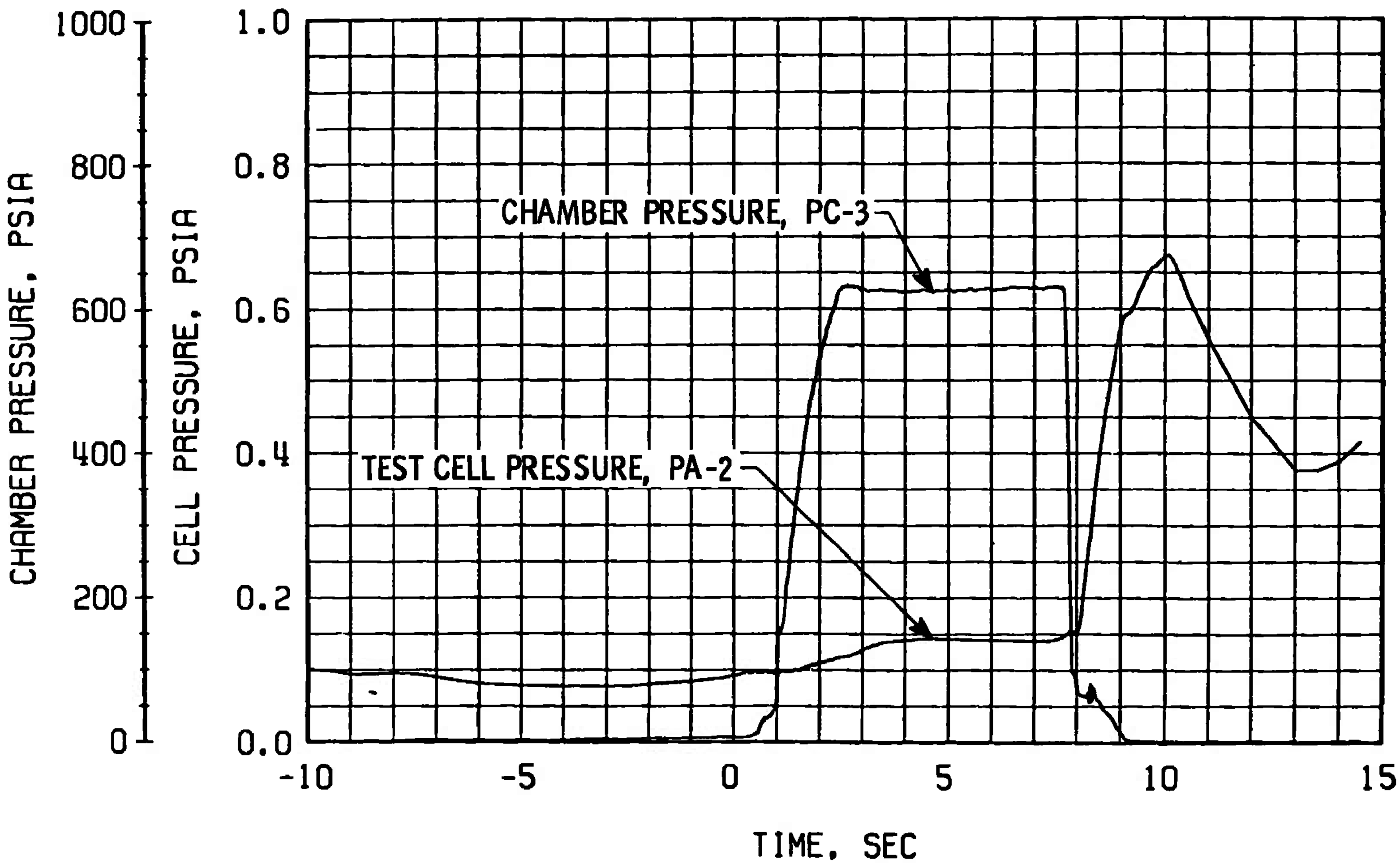
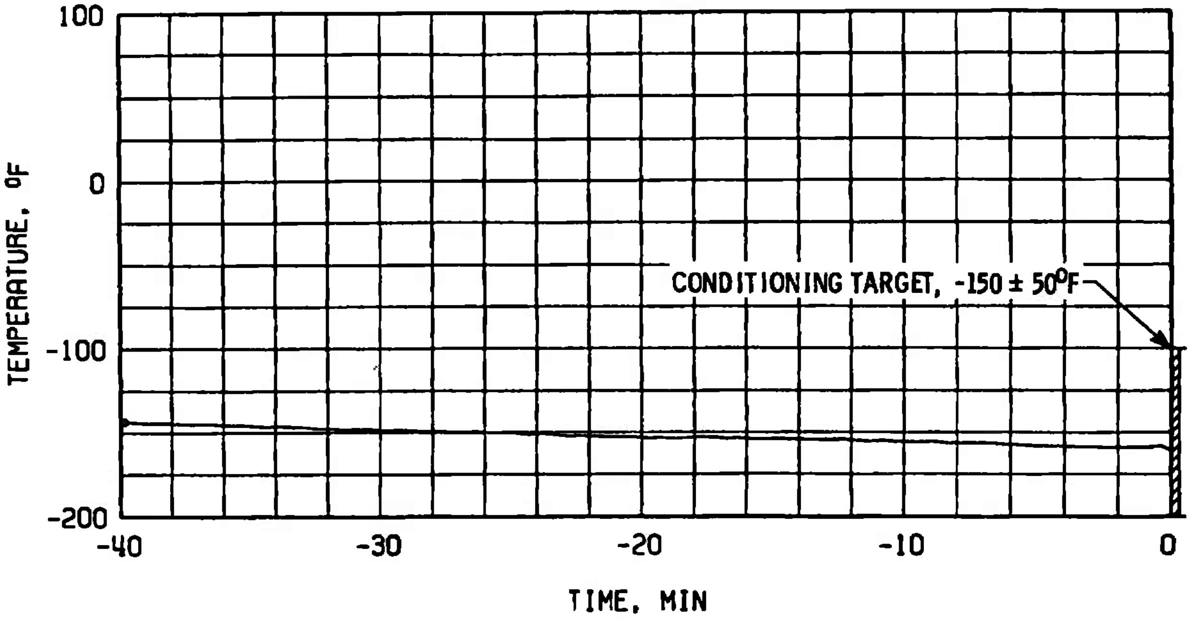
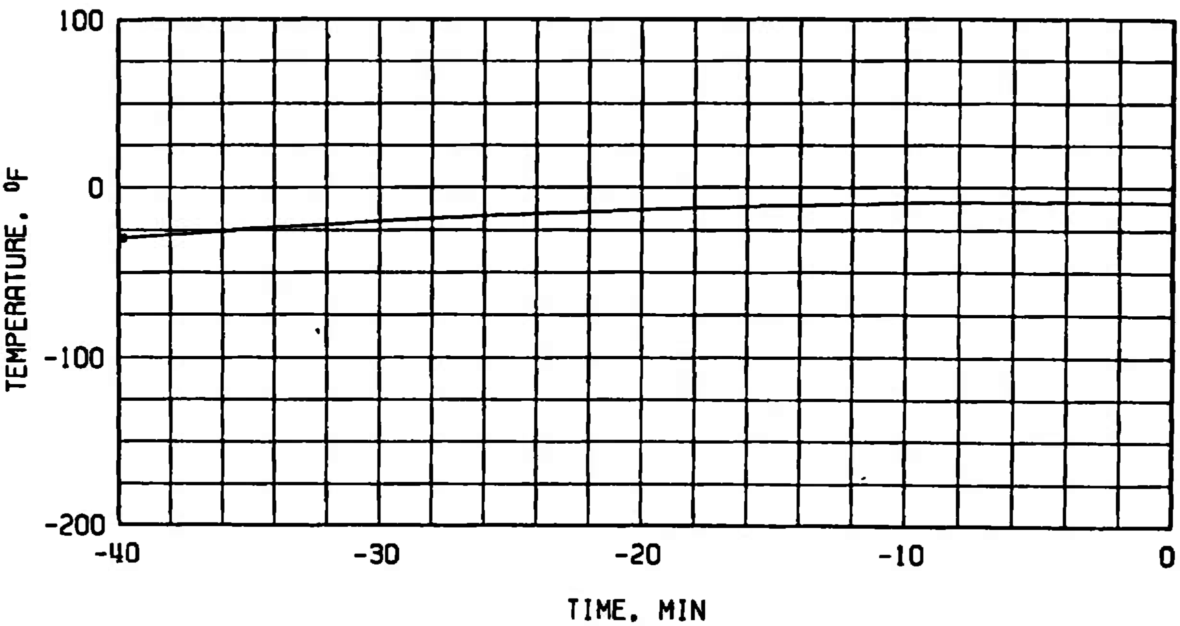


Fig. 44 Engine Ambient and Combustion Chamber Pressure, Firing 36B

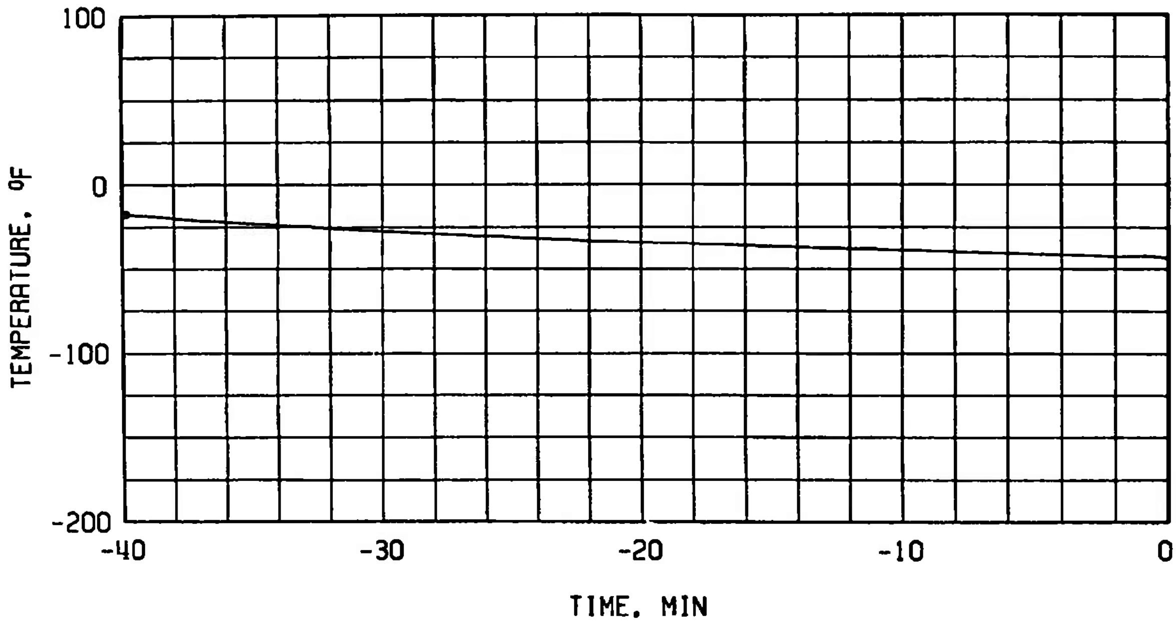


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

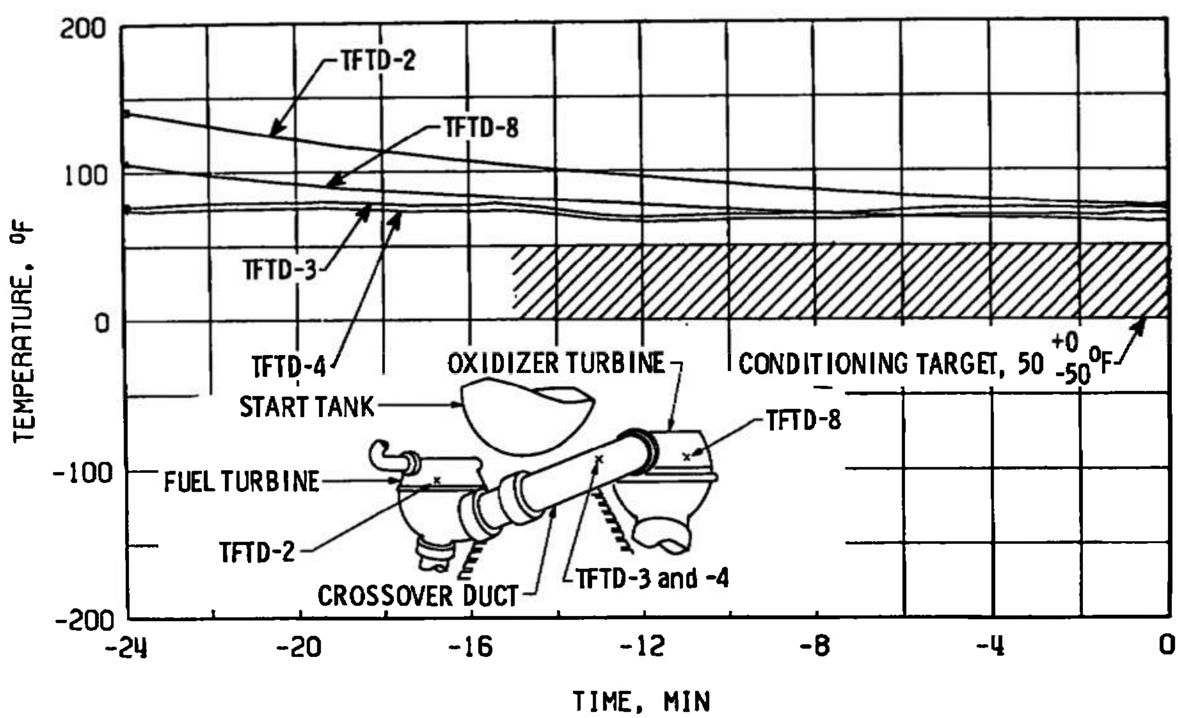


b. Gas Generator Body Temperature, TGGVRS

Fig. 45 Thermal Conditioning History of Engine Components, Firing 36C

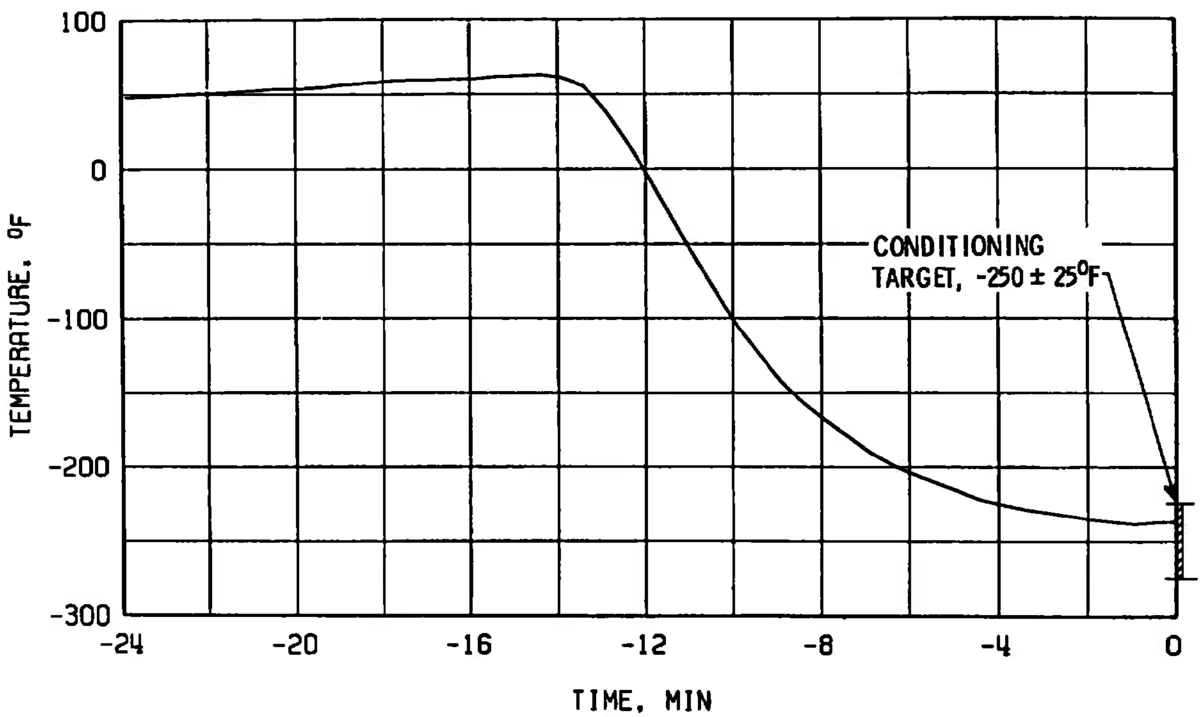


c. Start Tank Discharge Valve Opening Control, TSTDVOC

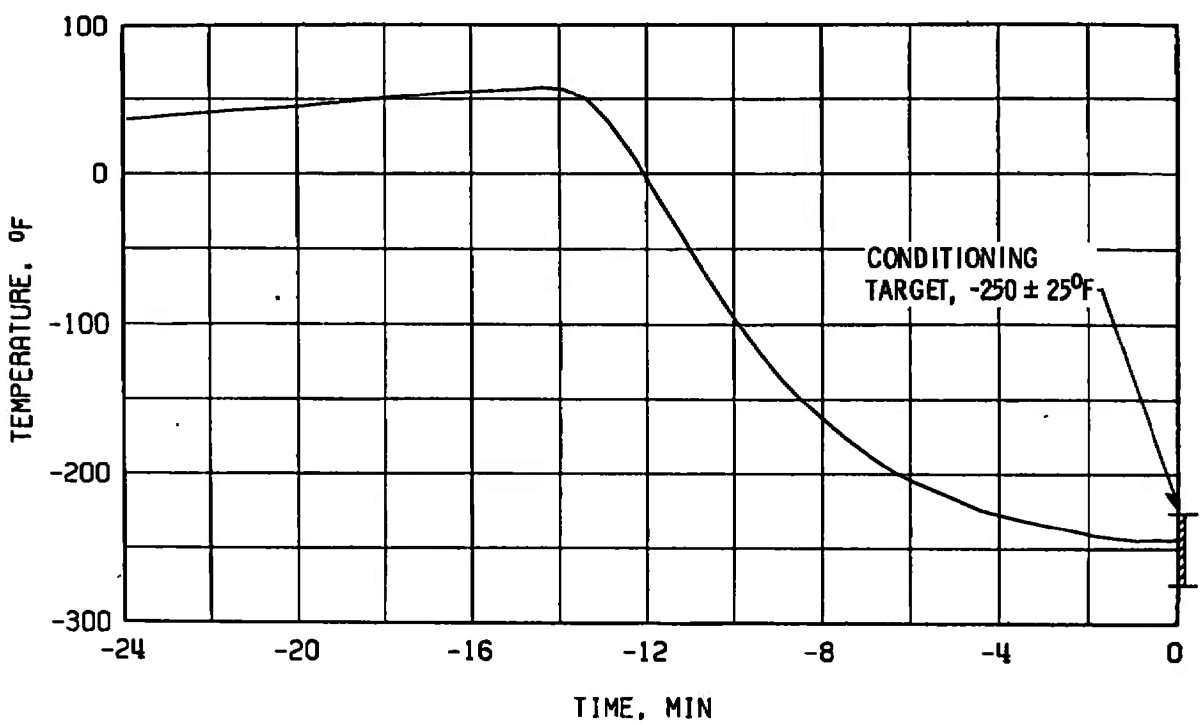


d. Crossover Duct, TFTD

Fig. 45 Continued

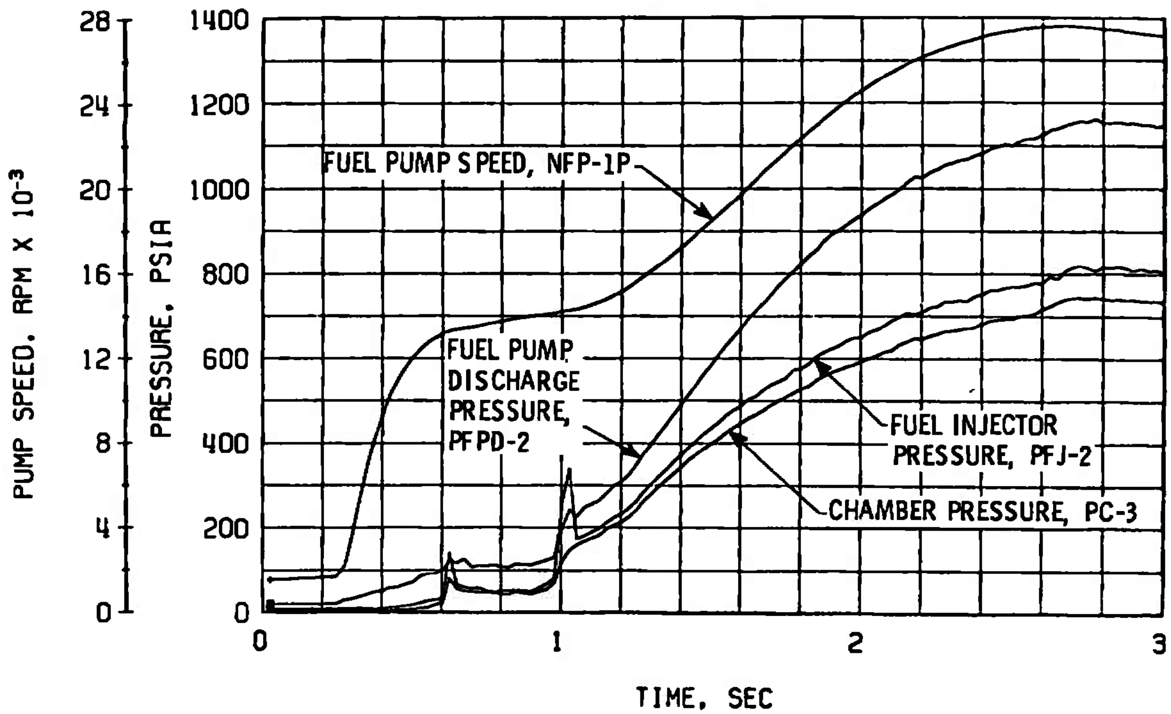


e. Thrust Chamber Throat, TTC-1P

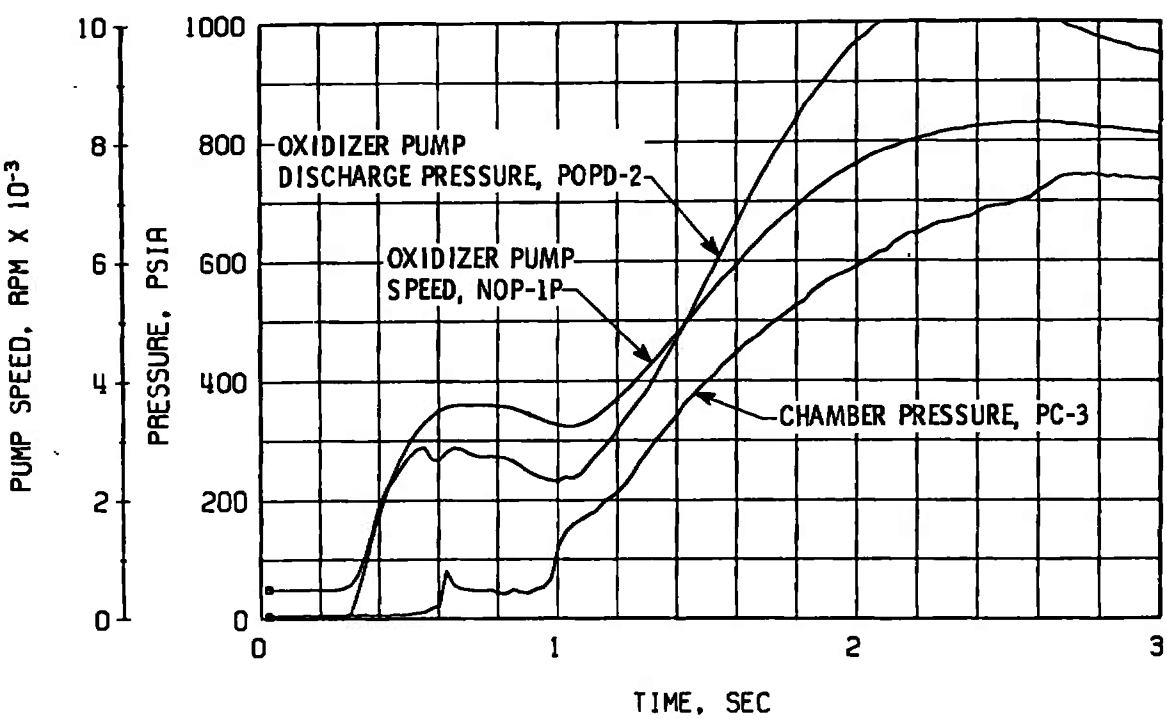


f. Thrust Chamber Throat, TTC-2

Fig. 45 Concluded

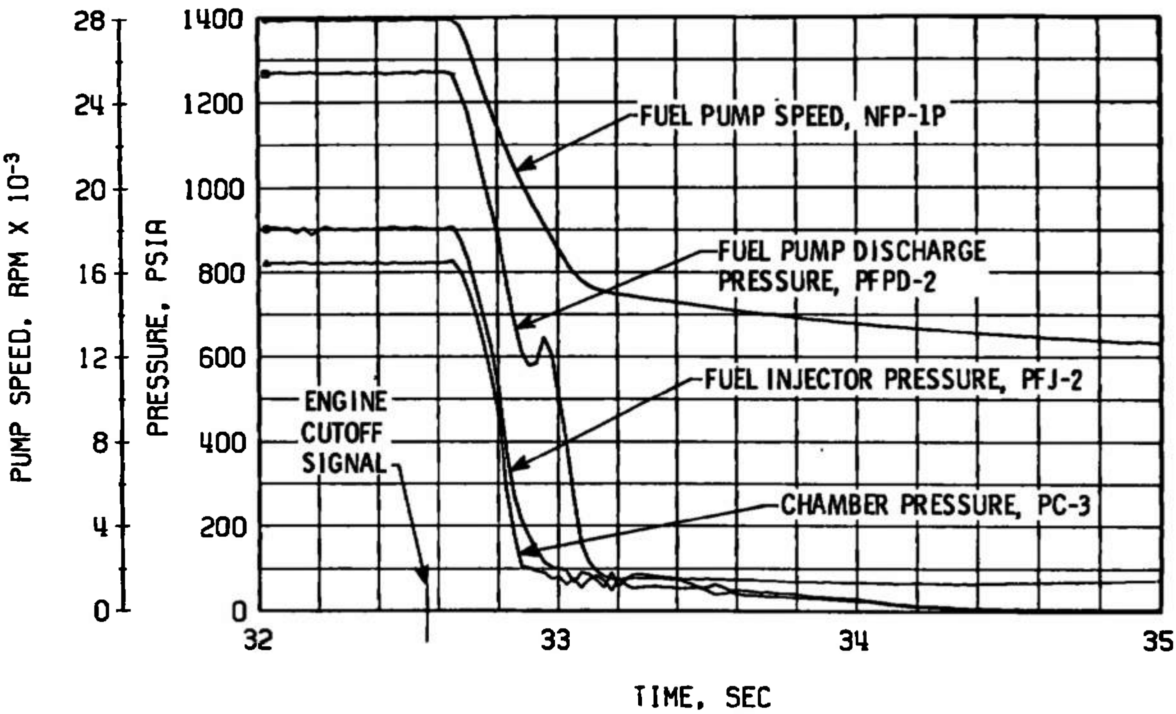


a. Thrust Chamber Fuel System, Start

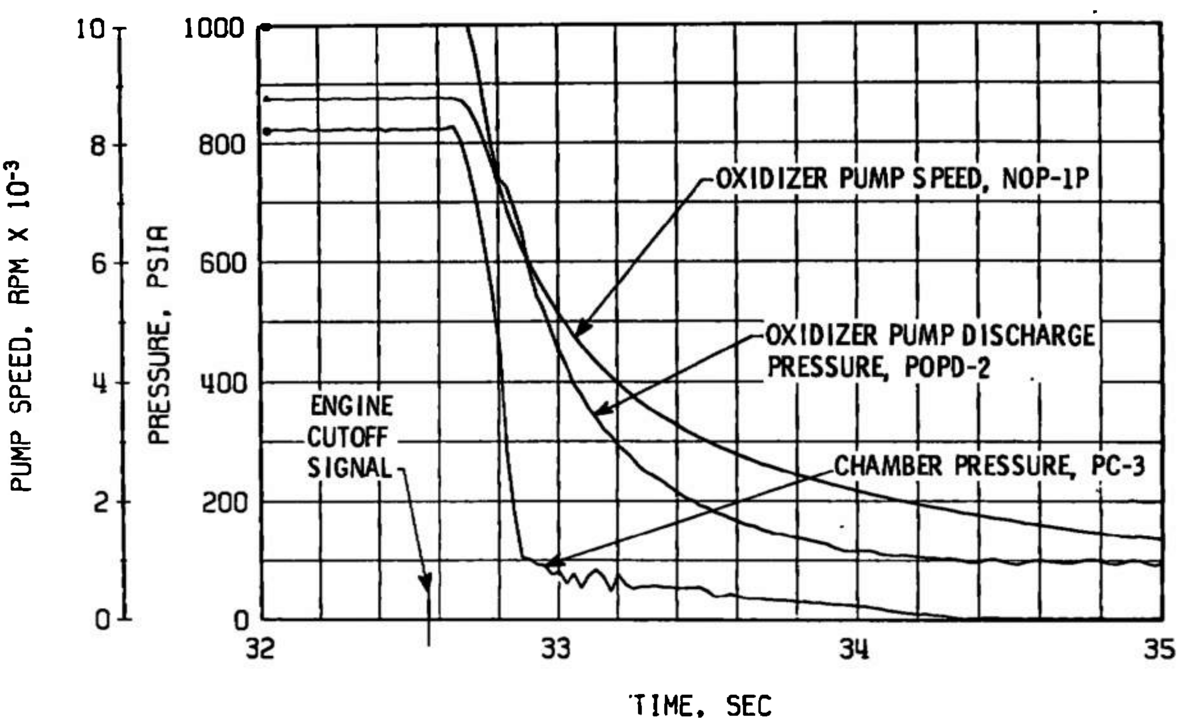


b. Thrust Chamber Oxidizer System, Start

Fig. 46 Engine Transient Operation, Firing 36C

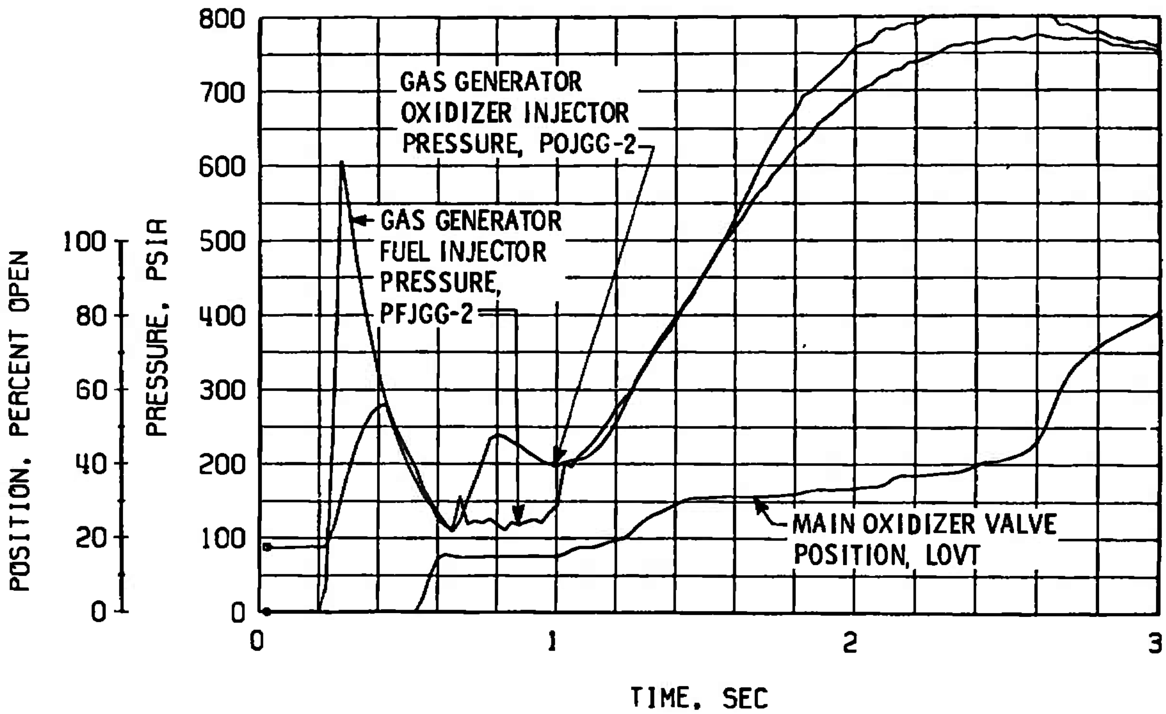


c. Thrust Chamber Fuel System, Shutdown

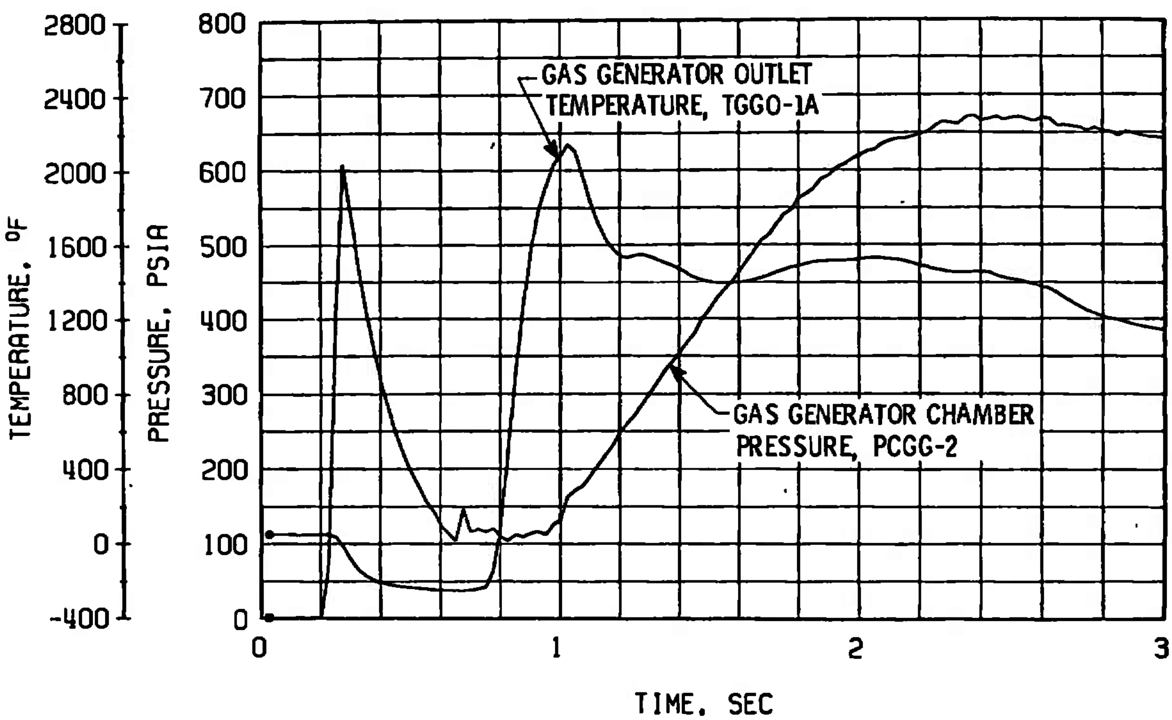


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 46 Continued

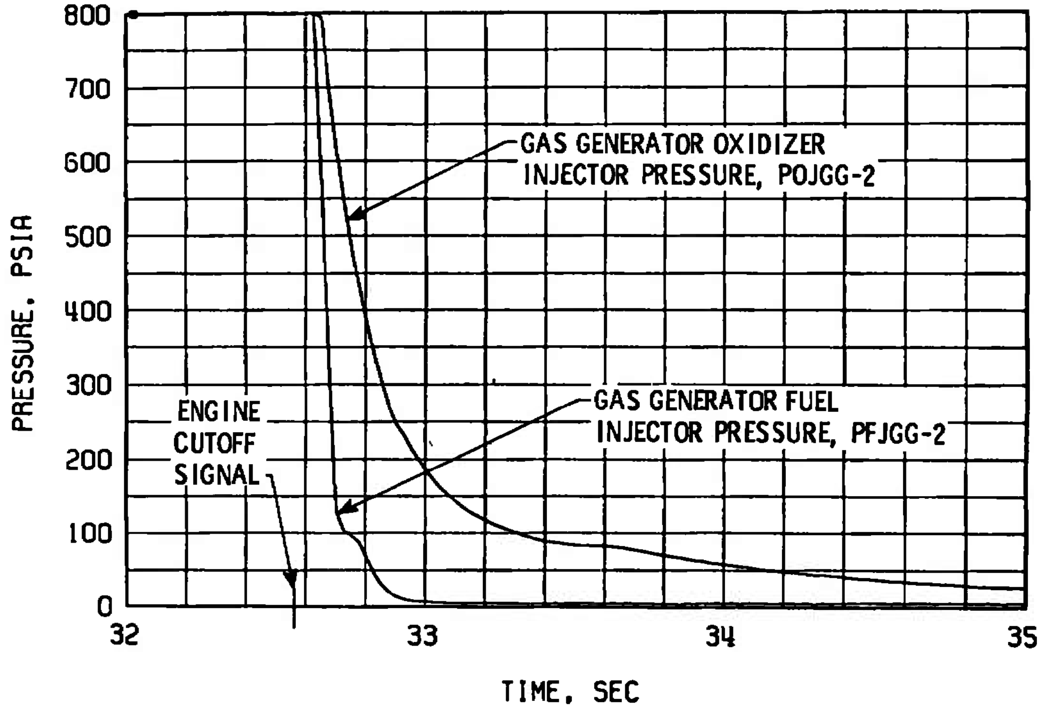


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

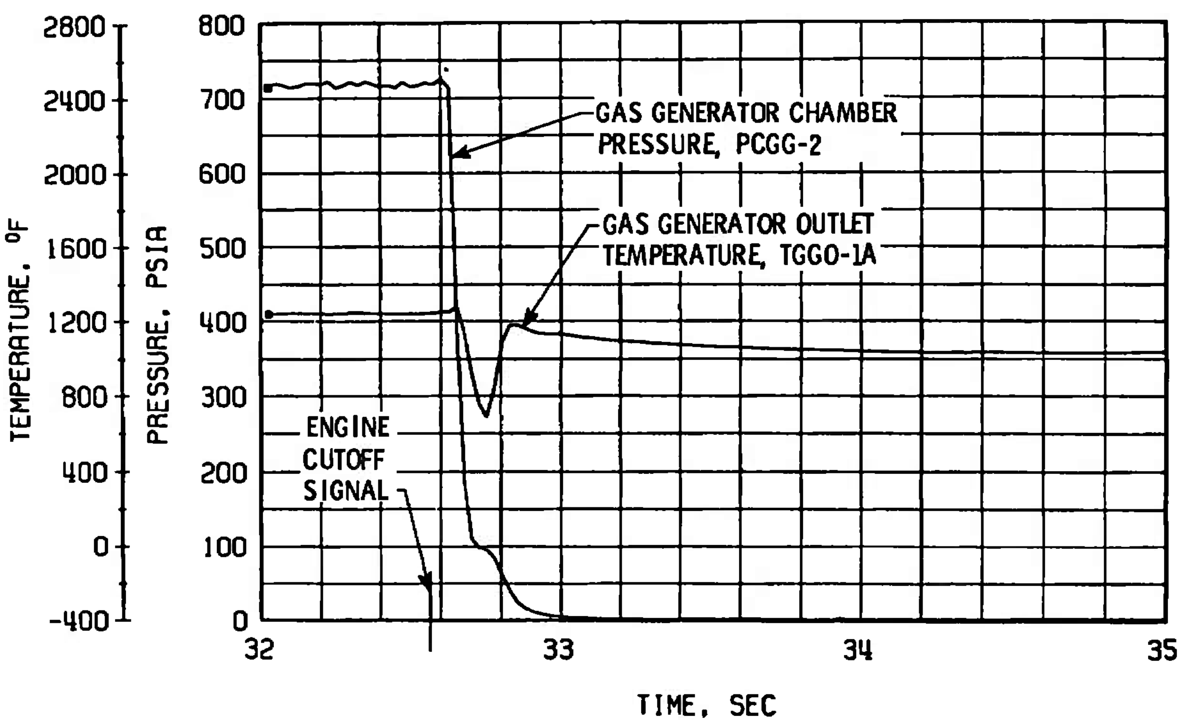


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 46 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 46 Concluded

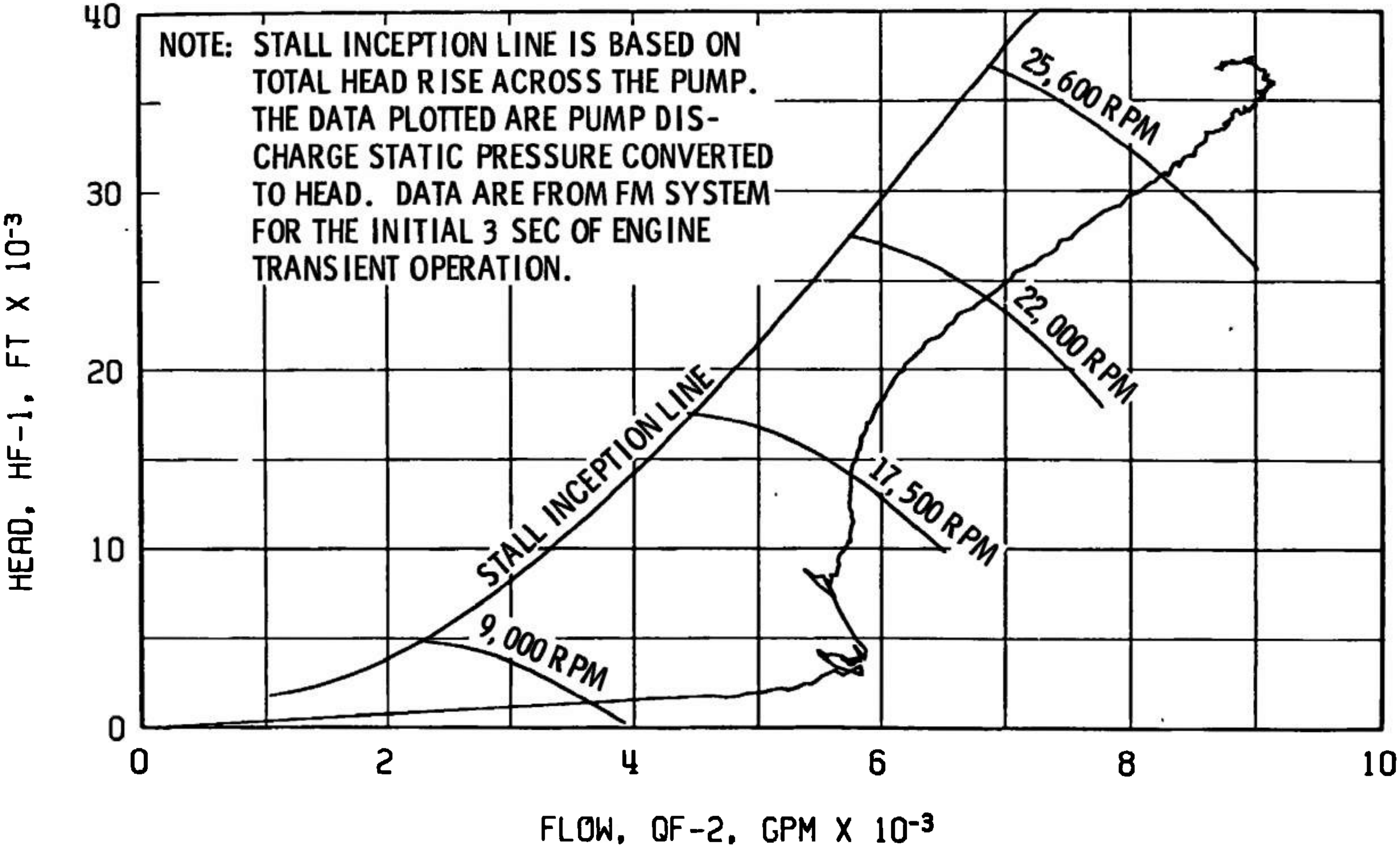


Fig. 47 Fuel Pump Start Transient Performance, Firing 36C

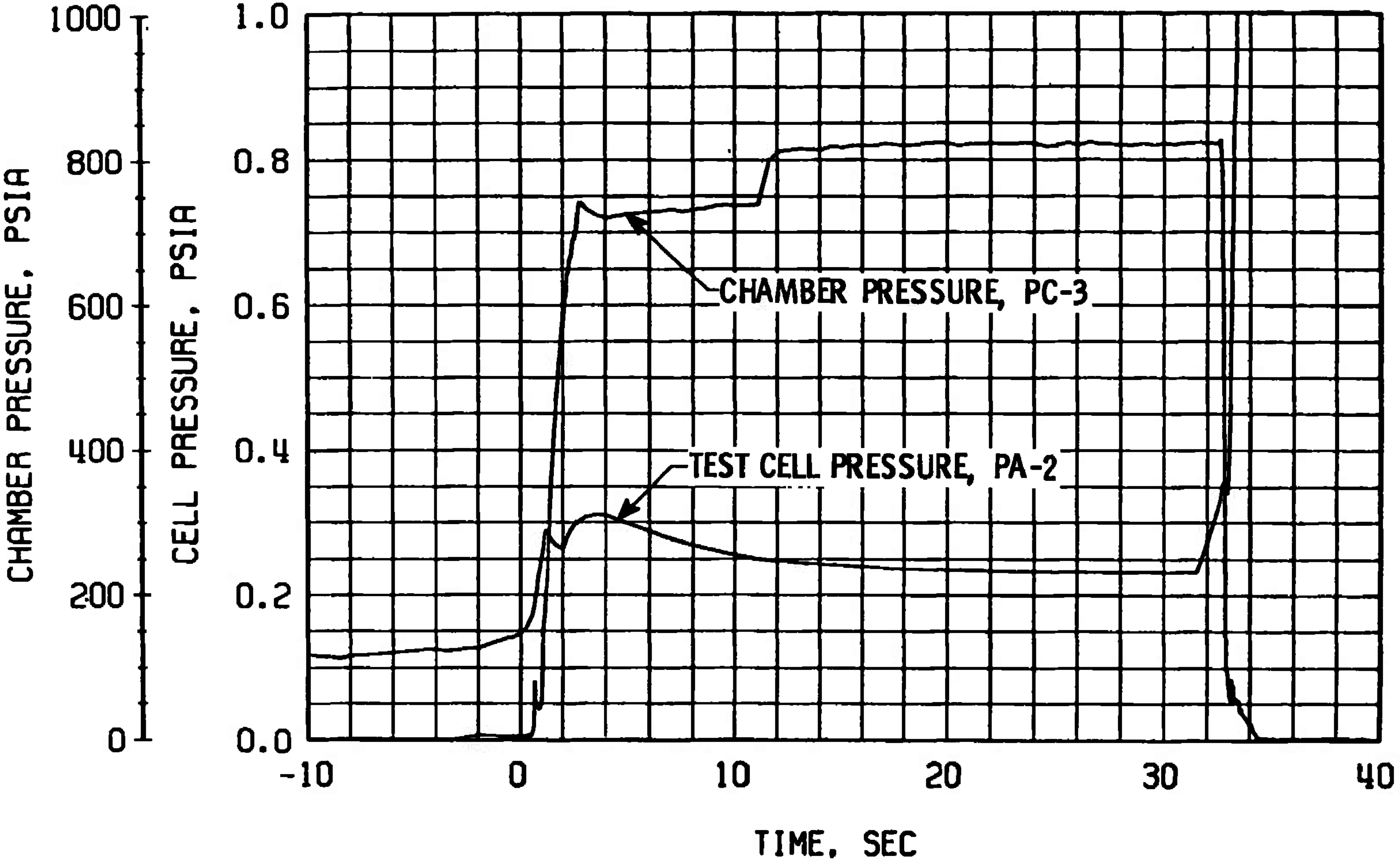
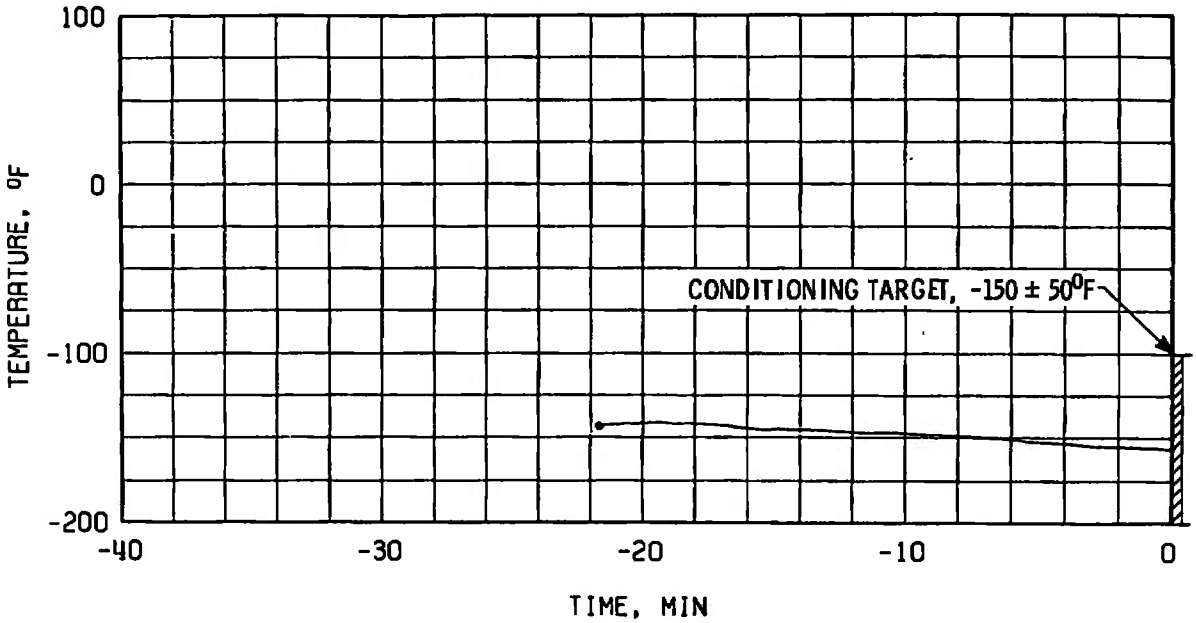
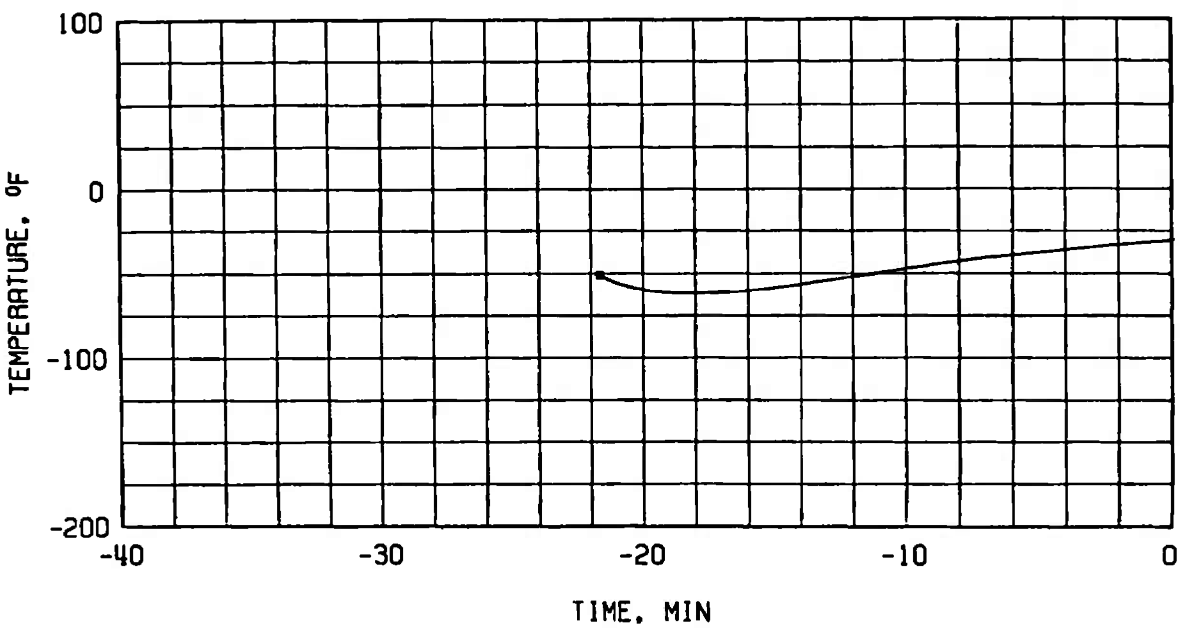


Fig. 48 Engine Ambient and Combustion Chamber Pressure, Firing 36C

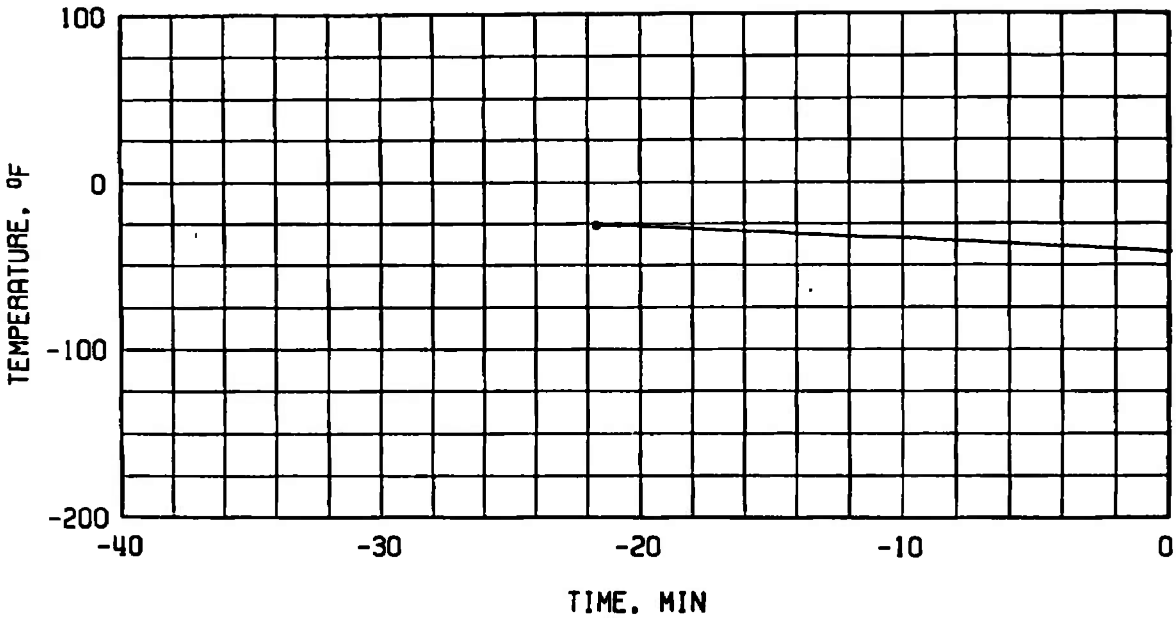


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

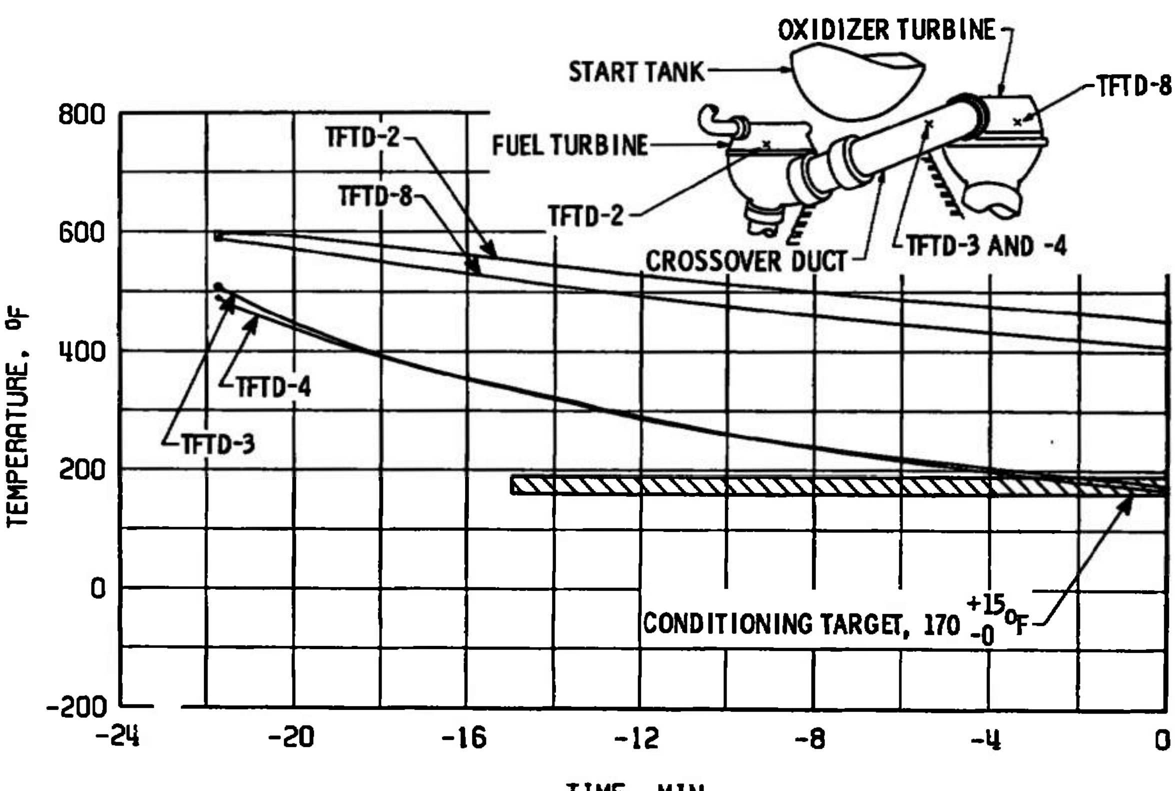


b. Gas Generator Body Temperature, TGGVRS

Fig. 49 Thermal Conditioning History of Engine Components, Firing 36D

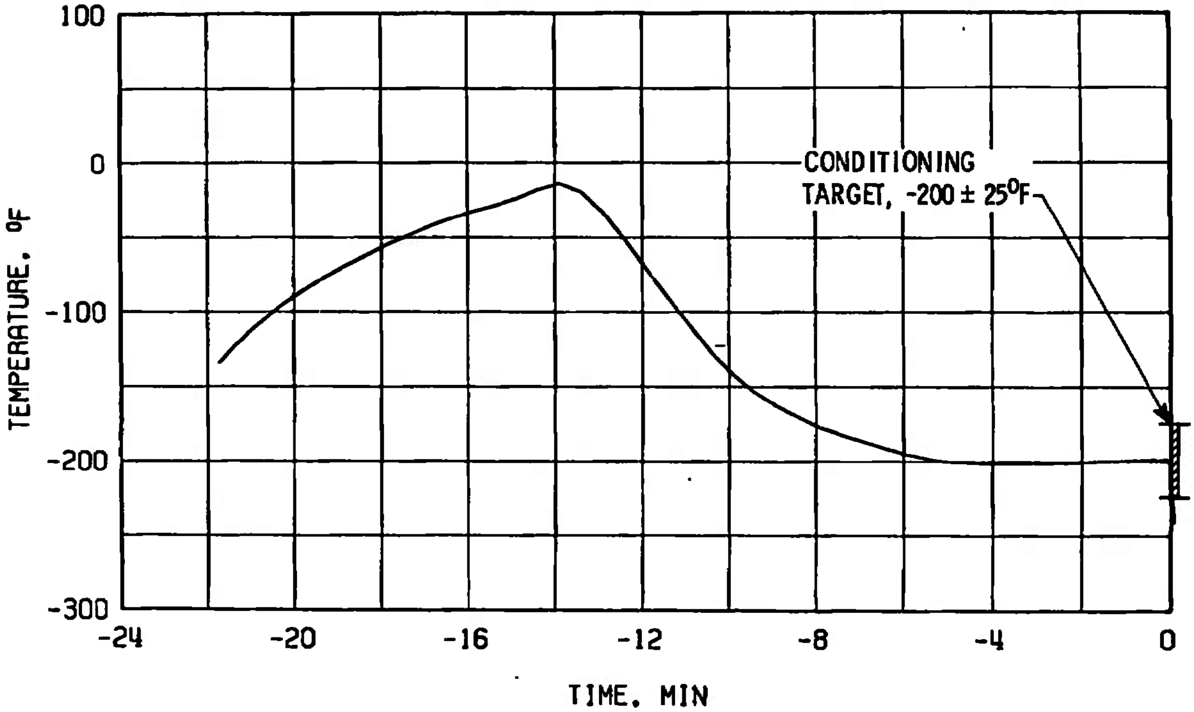


c. Start Tank Discharge Valve Opening Control, TSTDVOC

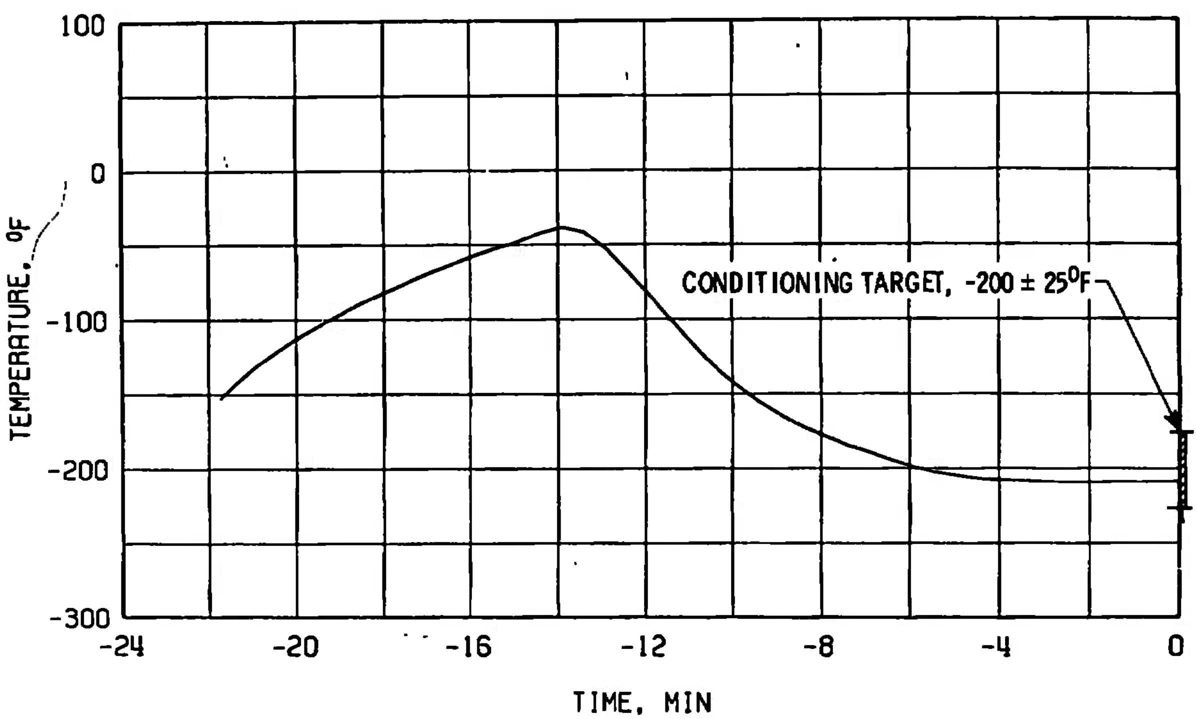


d. Crossover Duct, TFTD

Fig. 49 Continued

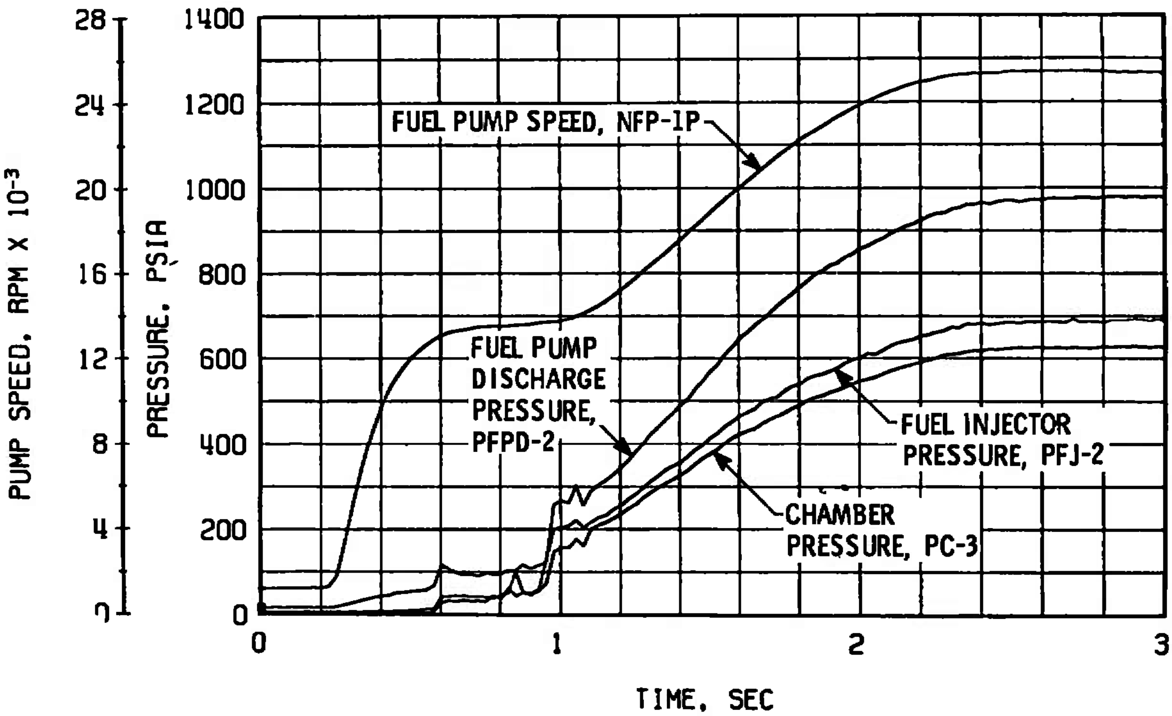


e. Thrust Chamber Throat, TTC-1P

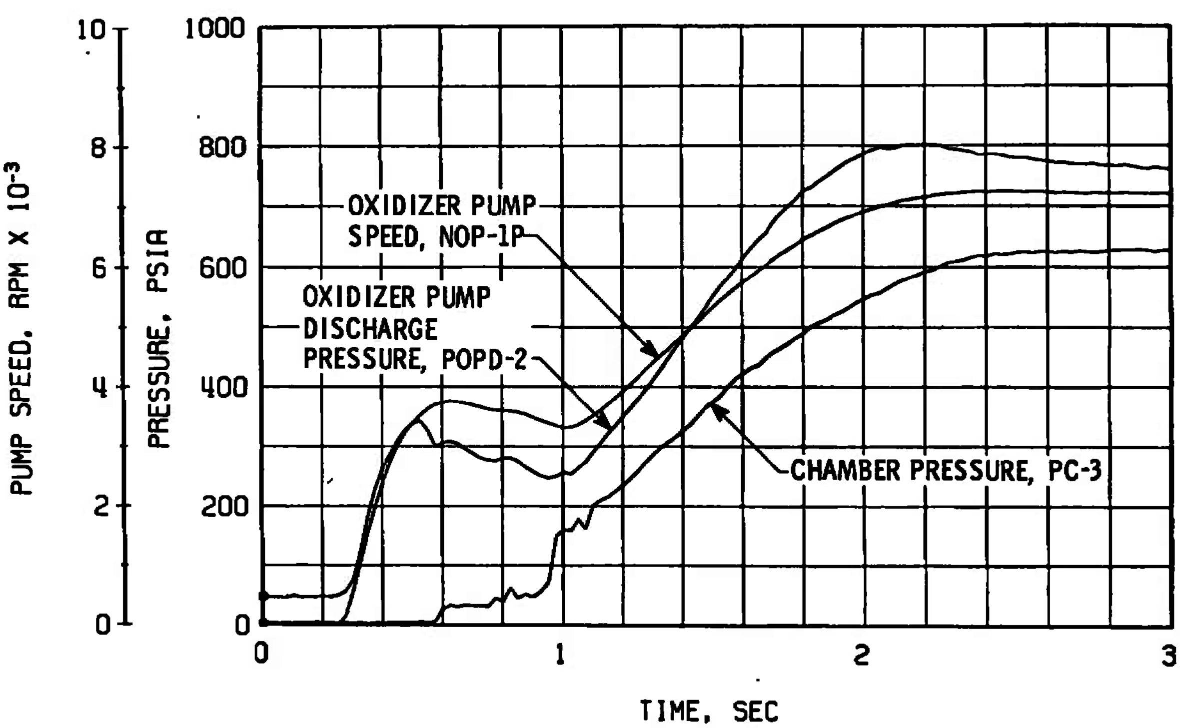


f. Thrust Chamber Throat, TTC-2

Fig. 49 Concluded

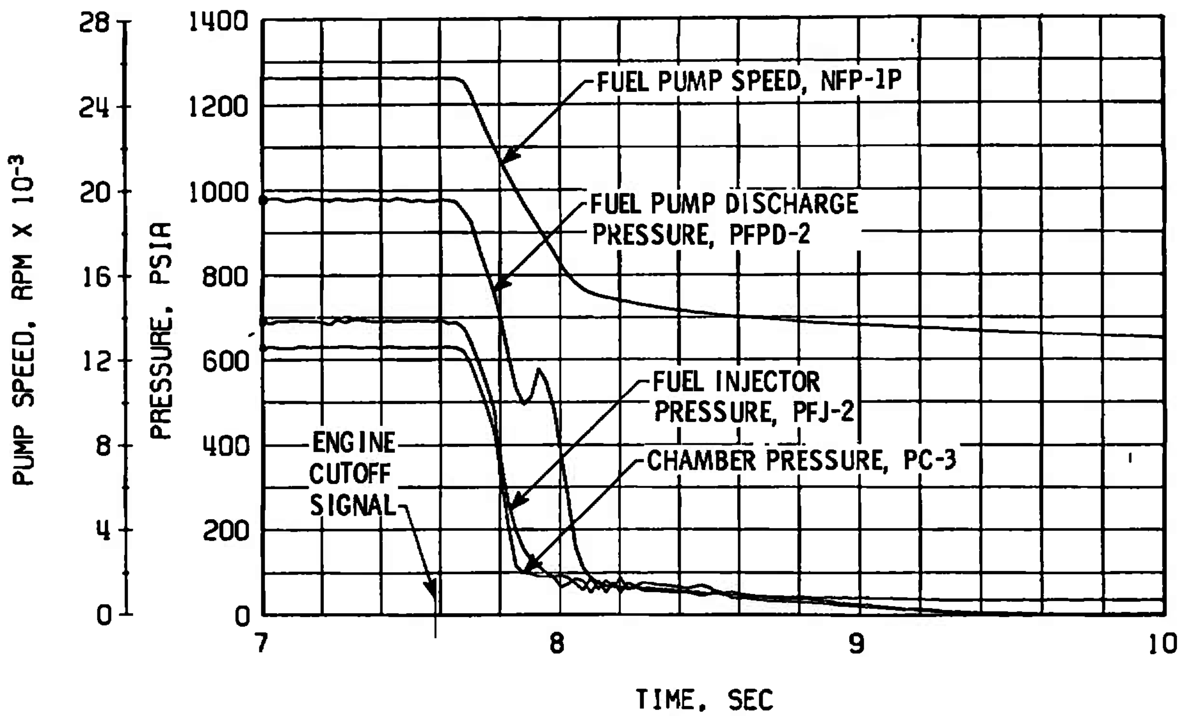


a. Thrust Chamber Fuel System, Start

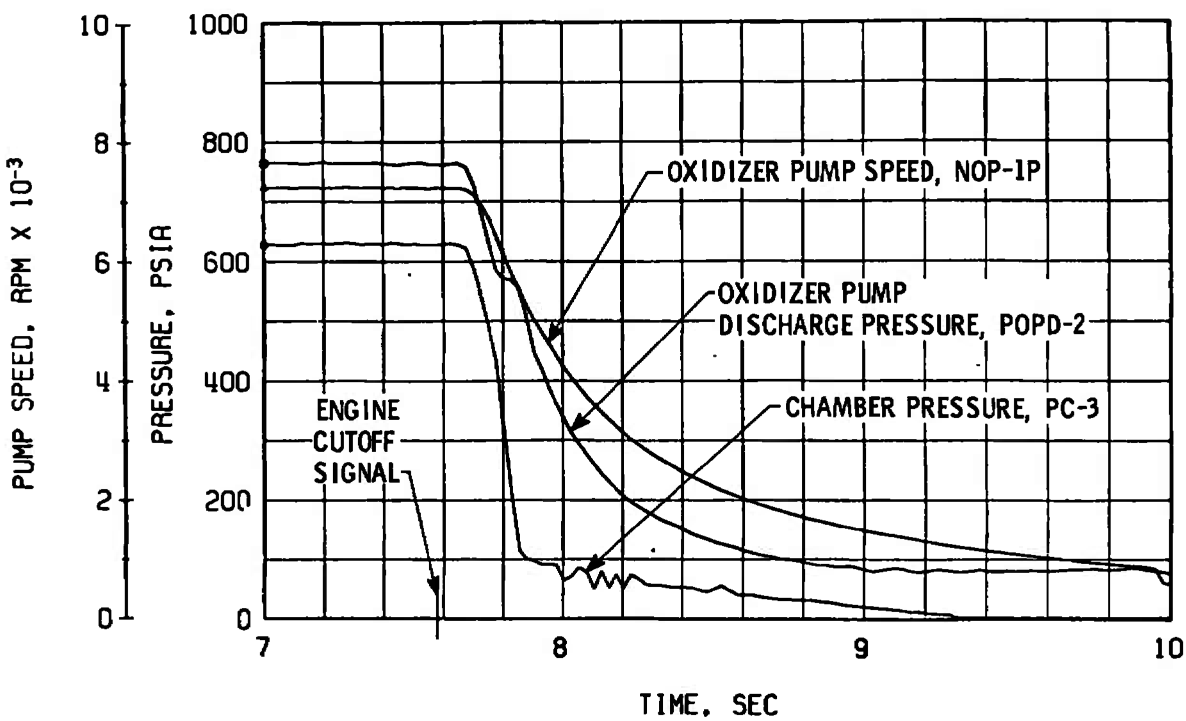


b. Thrust Chamber Oxidizer System, Start

Fig. 50 Engine Transient Operation, Firing 36D

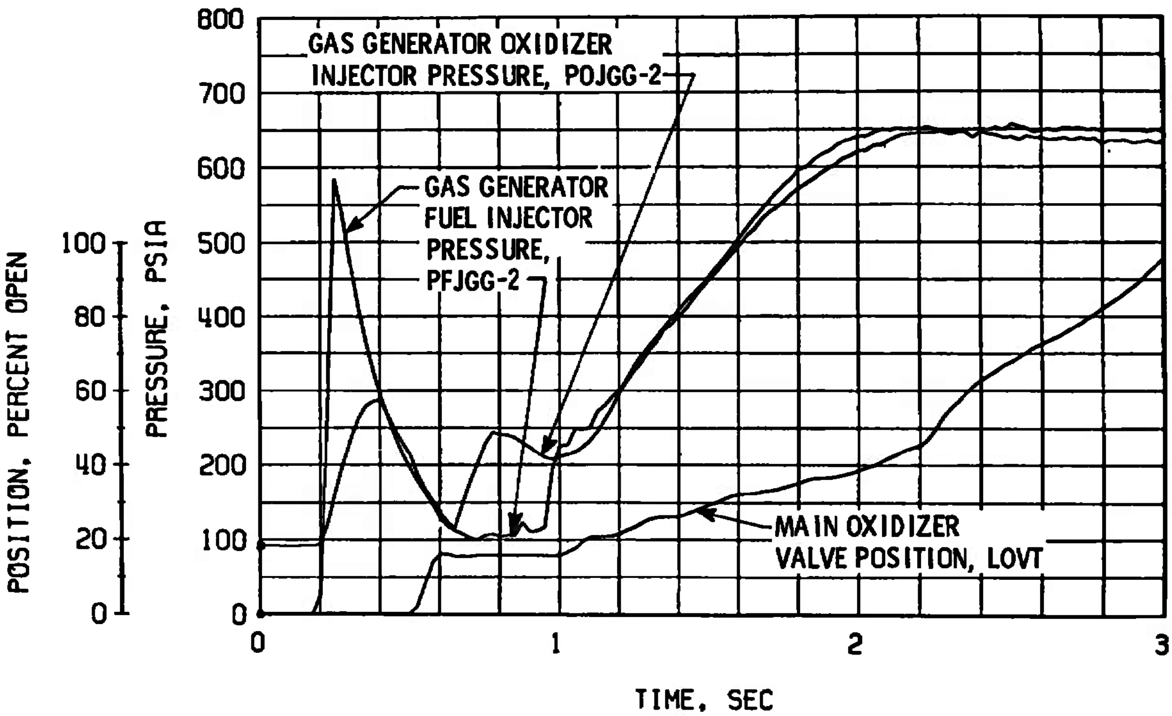


c. Thrust Chamber Fuel System, Shutdown

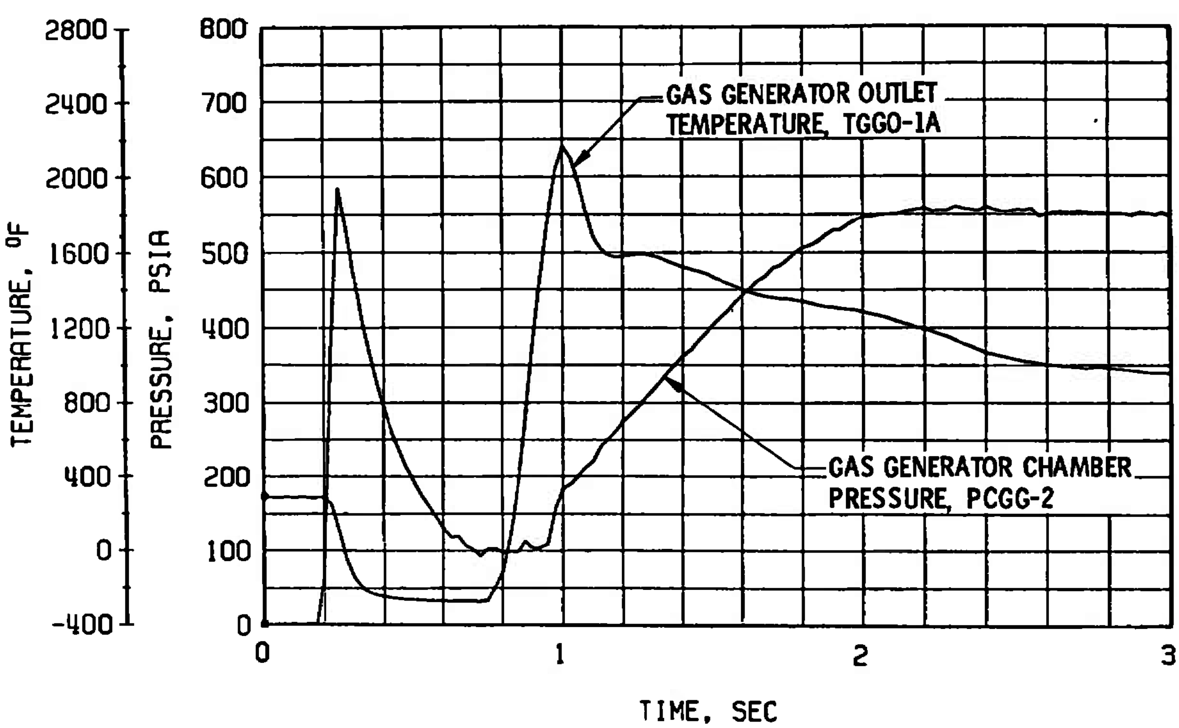


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 50 Continued

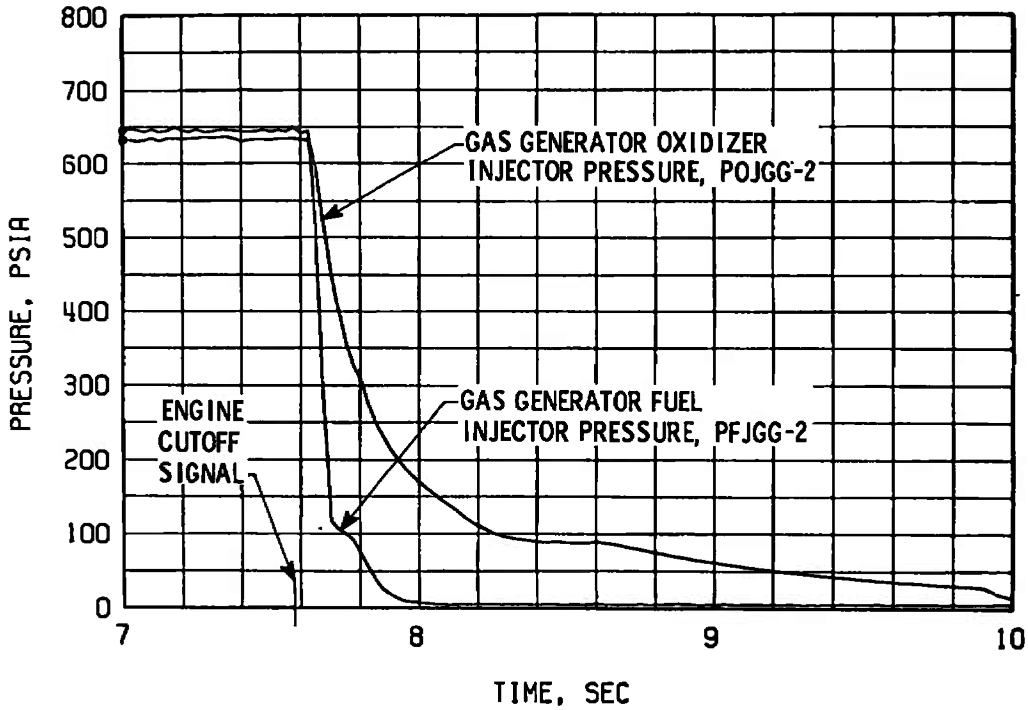


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

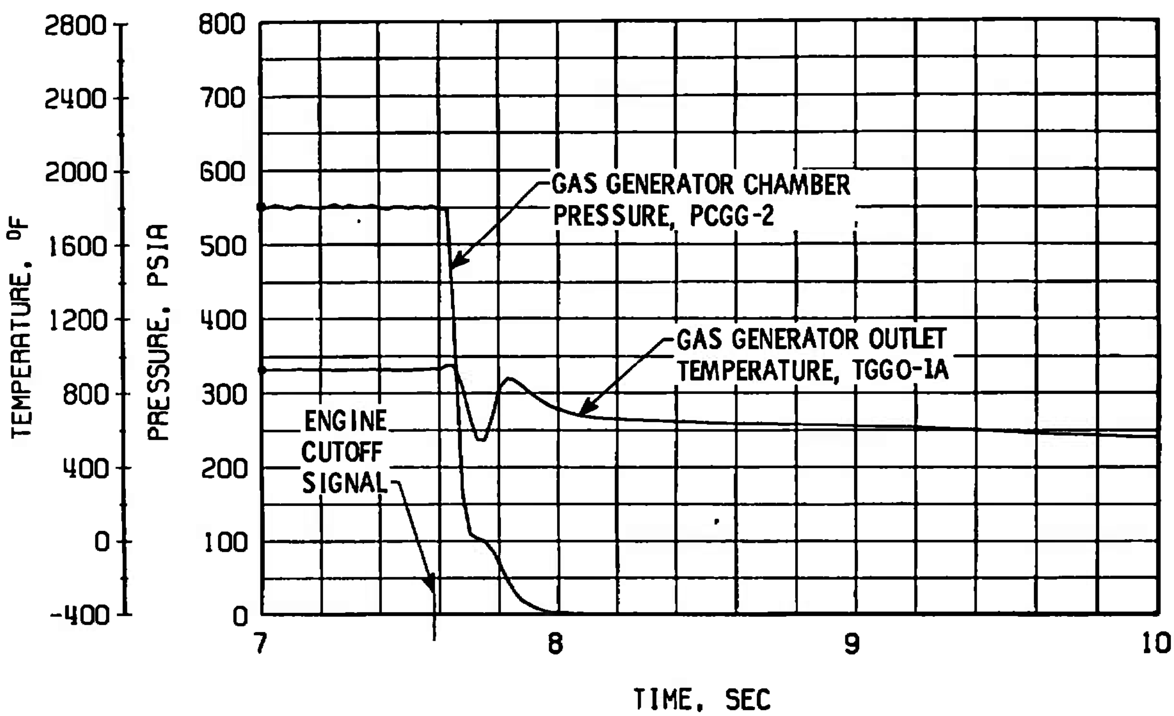


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 50 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 50 Concluded

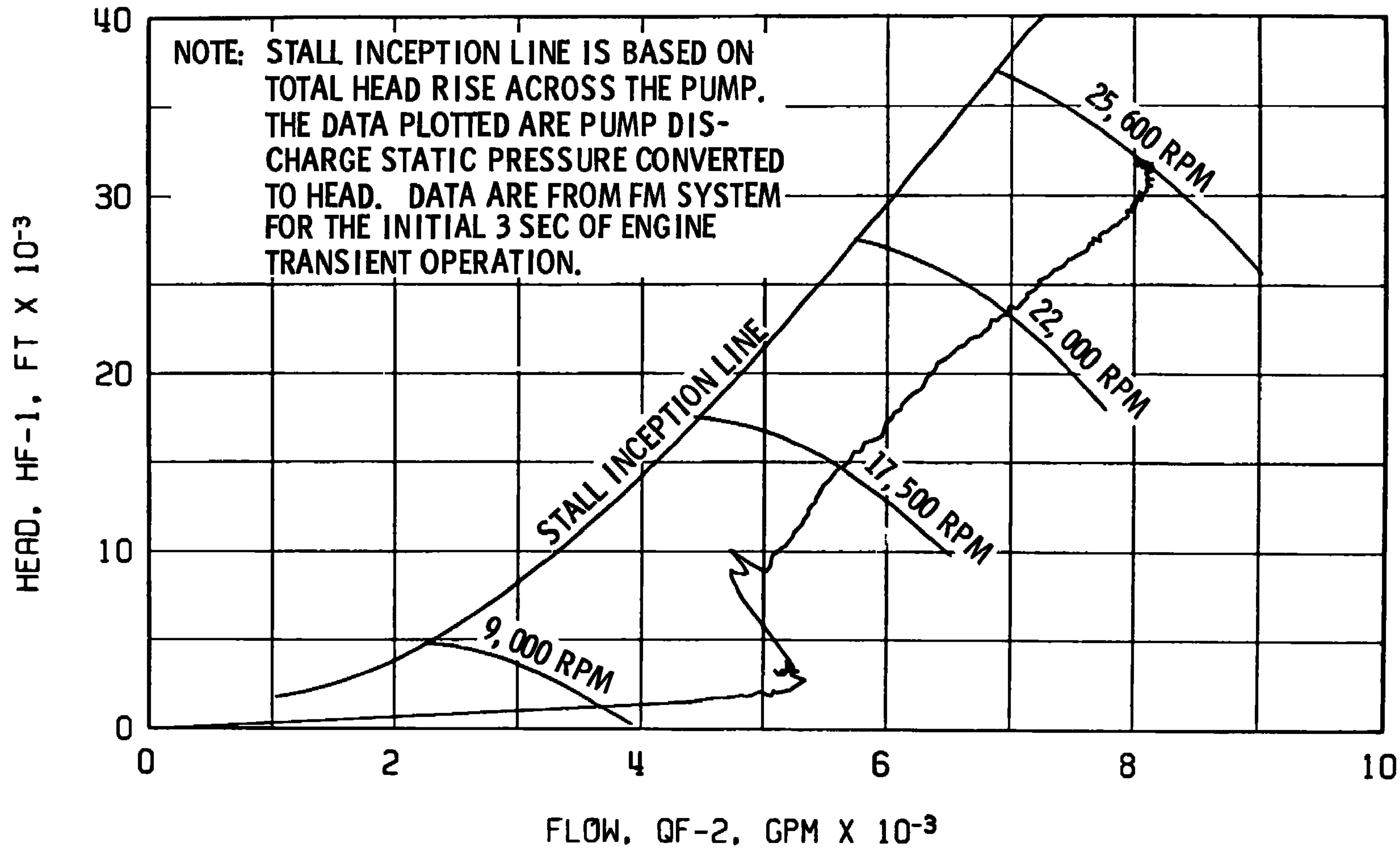


Fig. 51 Fuel Pump Start Transient Performance, Firing 36D

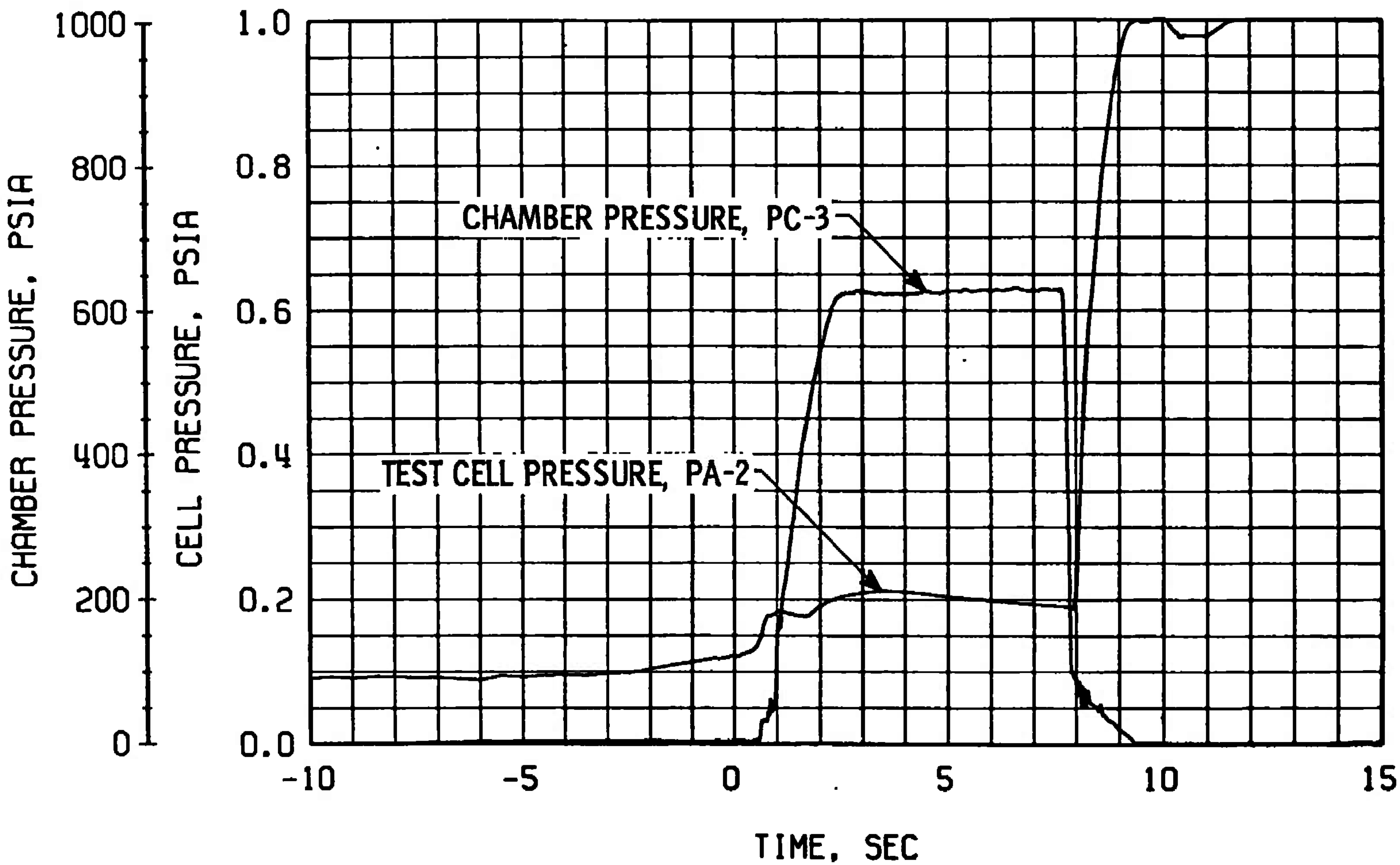
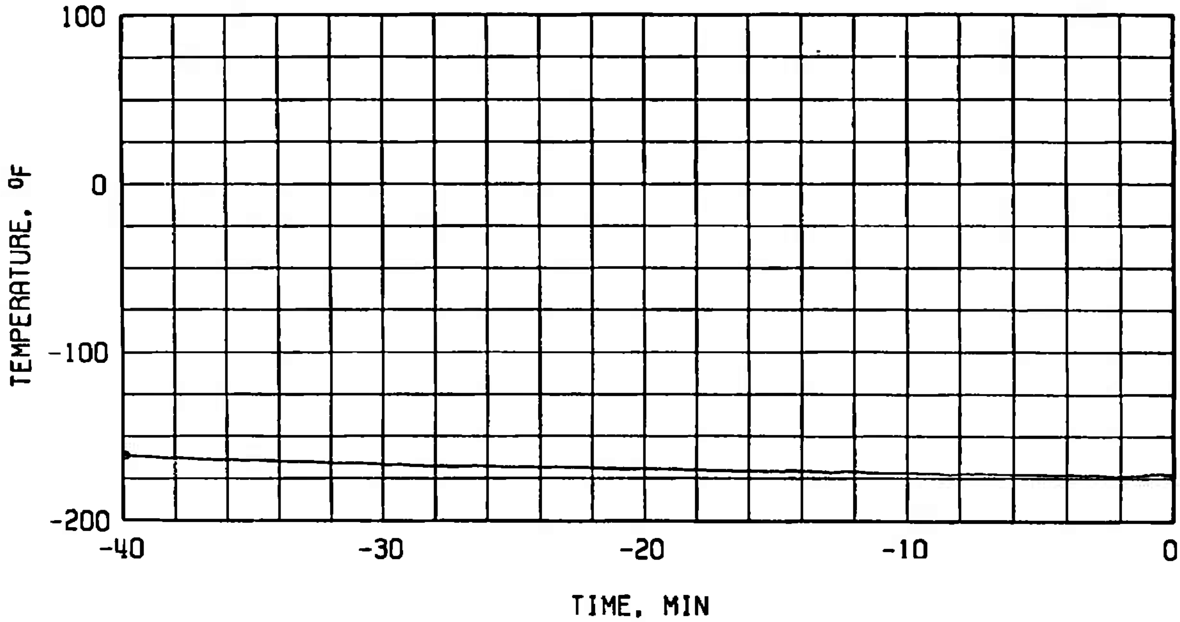
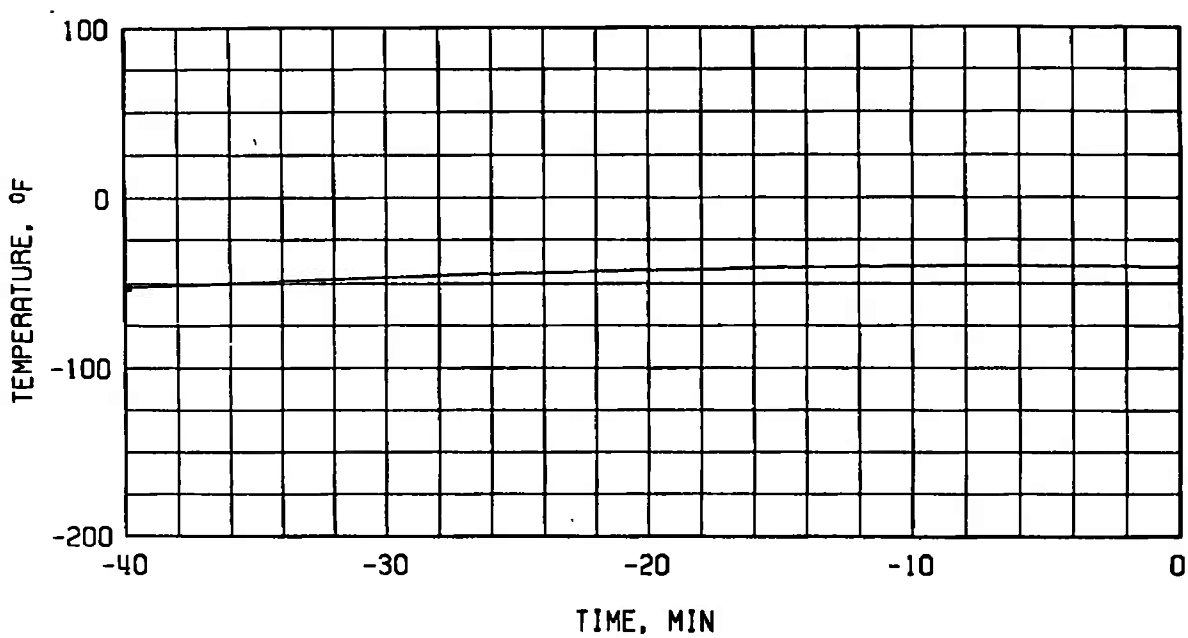


Fig. 52 Engine Ambient and Combustion Chamber Pressure, Firing 36D

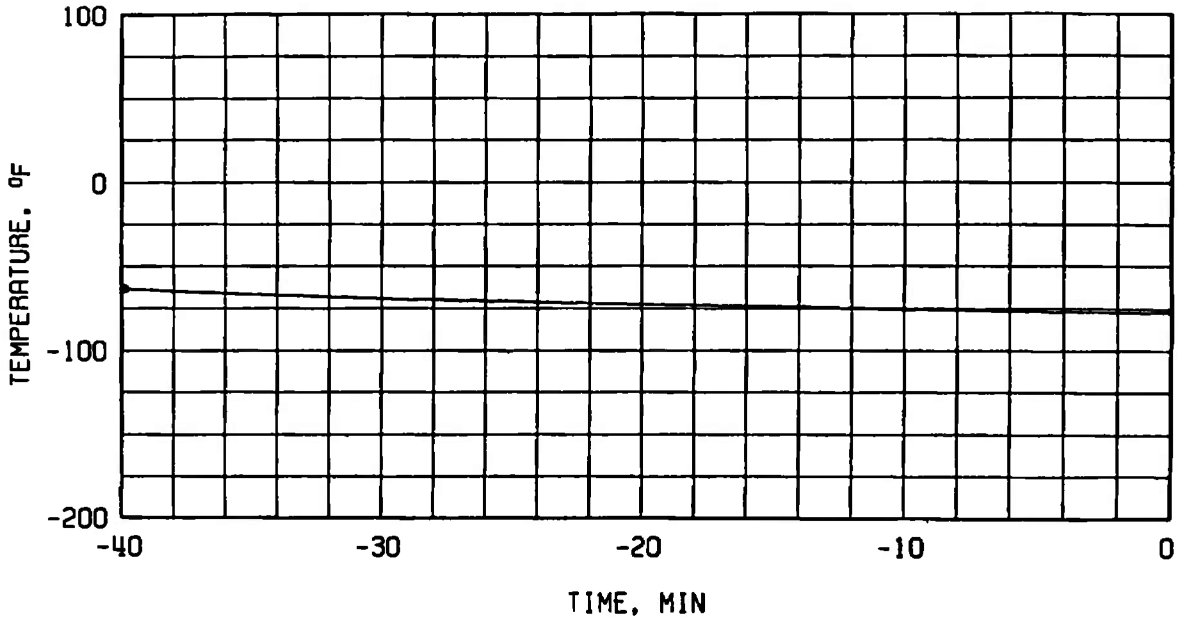


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

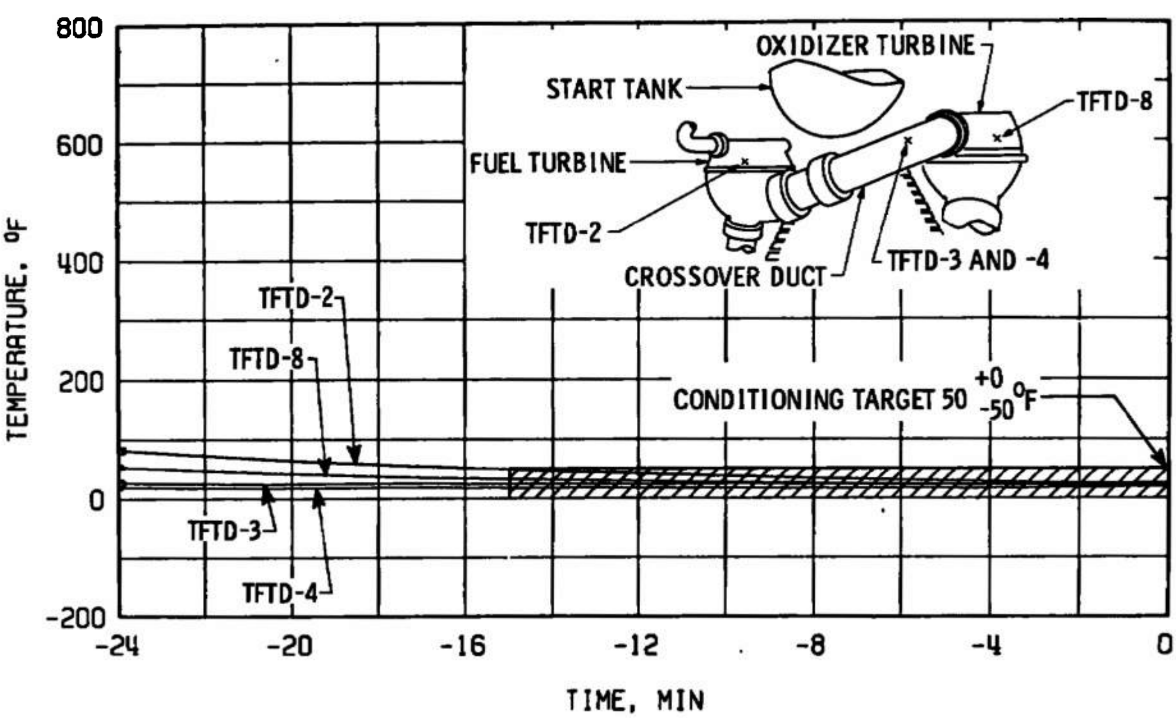


b. Gas Generator Body Temperature, TGGVRS

Fig. 53 Thermal Conditioning History of Engine Components, Firing 36E

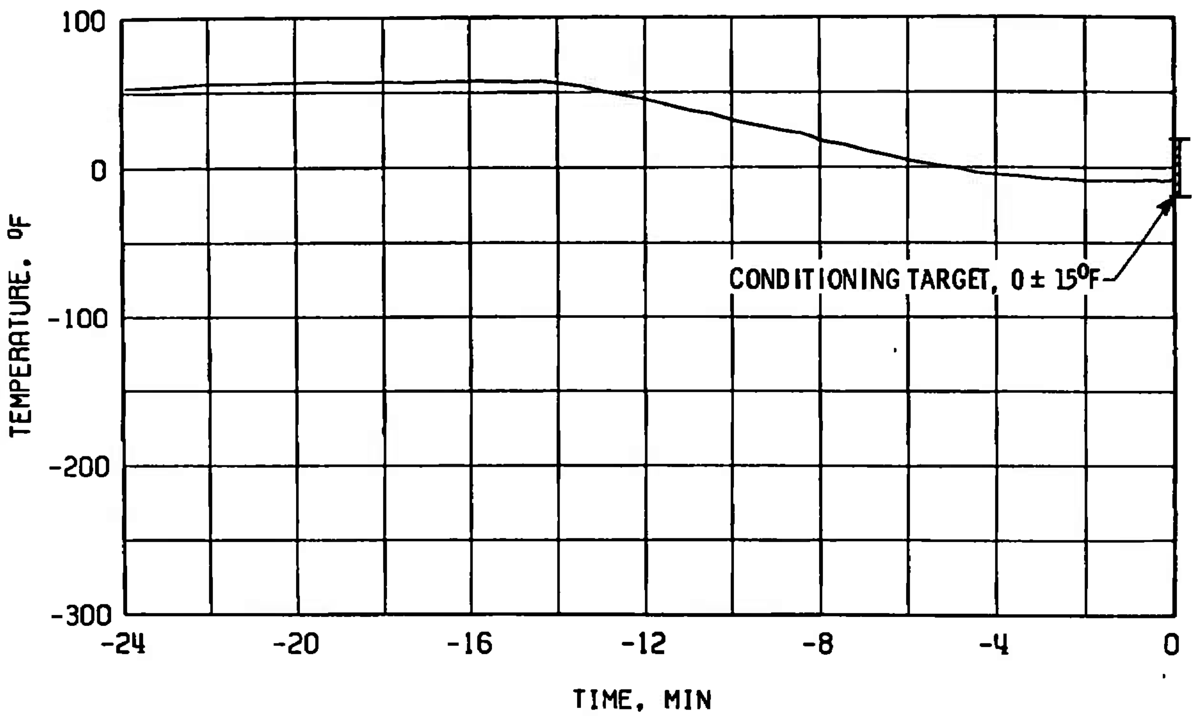


c. Start Tank Discharge Valve Opening Control Temperature, TSTDVOC

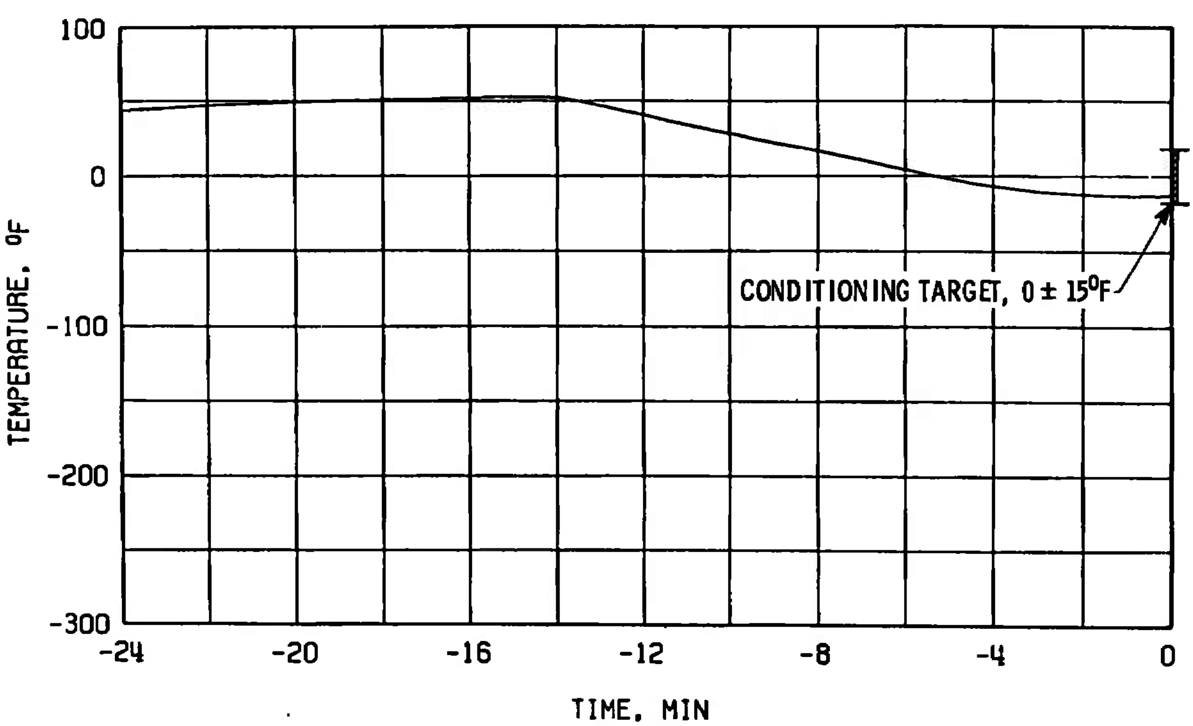


d. Crossover Duct, TFTD

Fig. 53 Continued

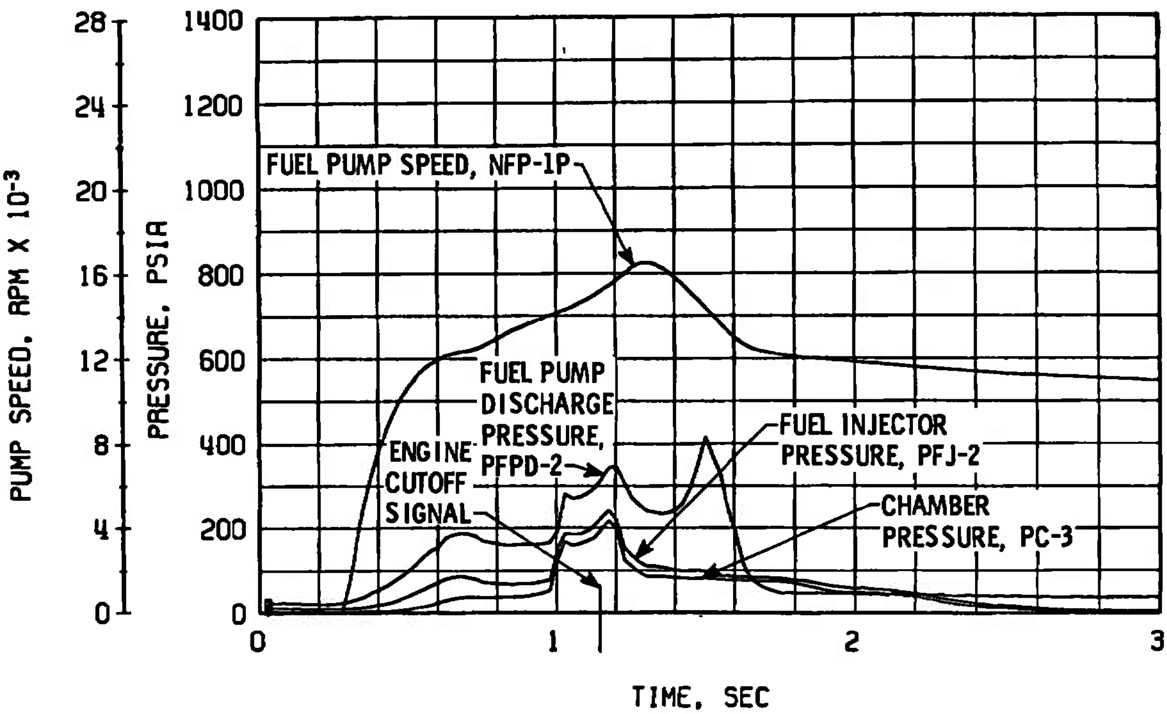


e. Thrust Chamber Throat, TTC-1P

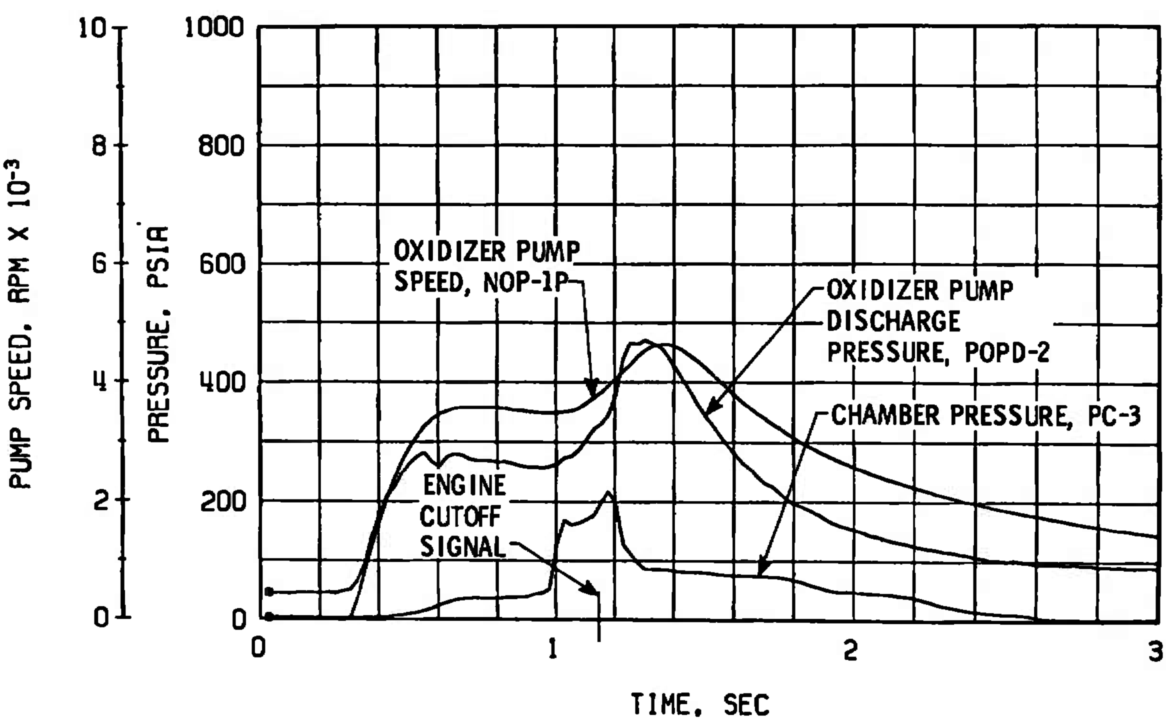


f. Thrust Chamber Throat, TTC-2

Fig. 53 Concluded

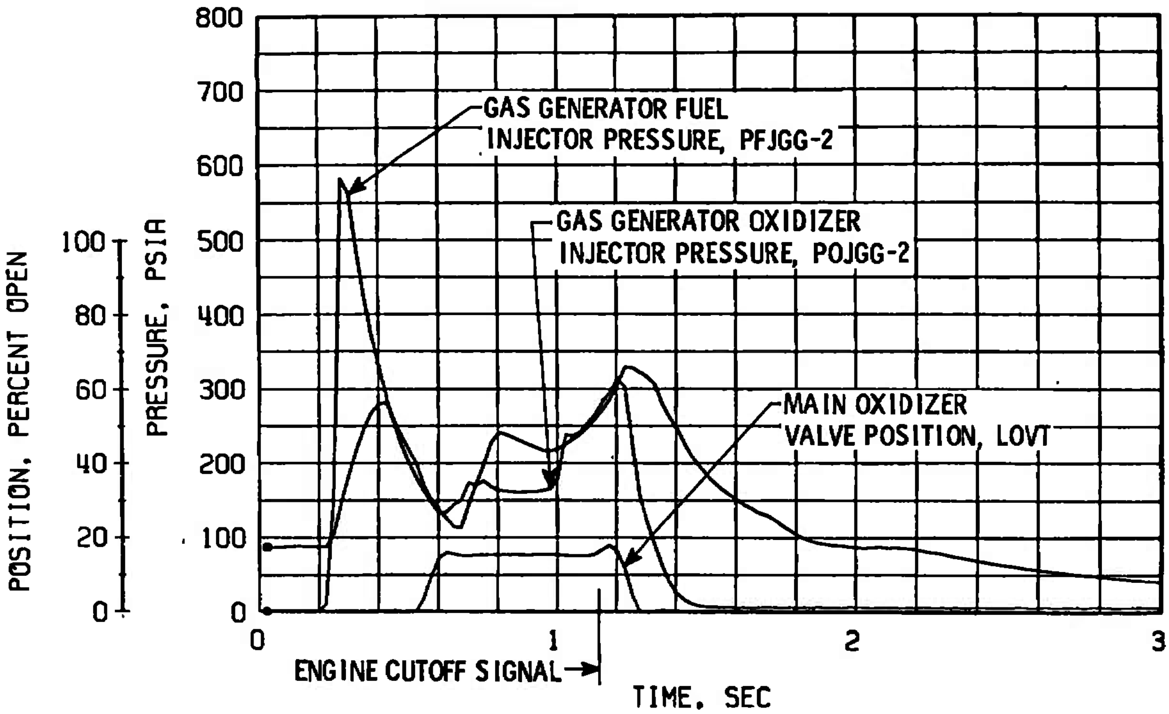


a. Thrust Chamber Fuel System, Start and Shutdown

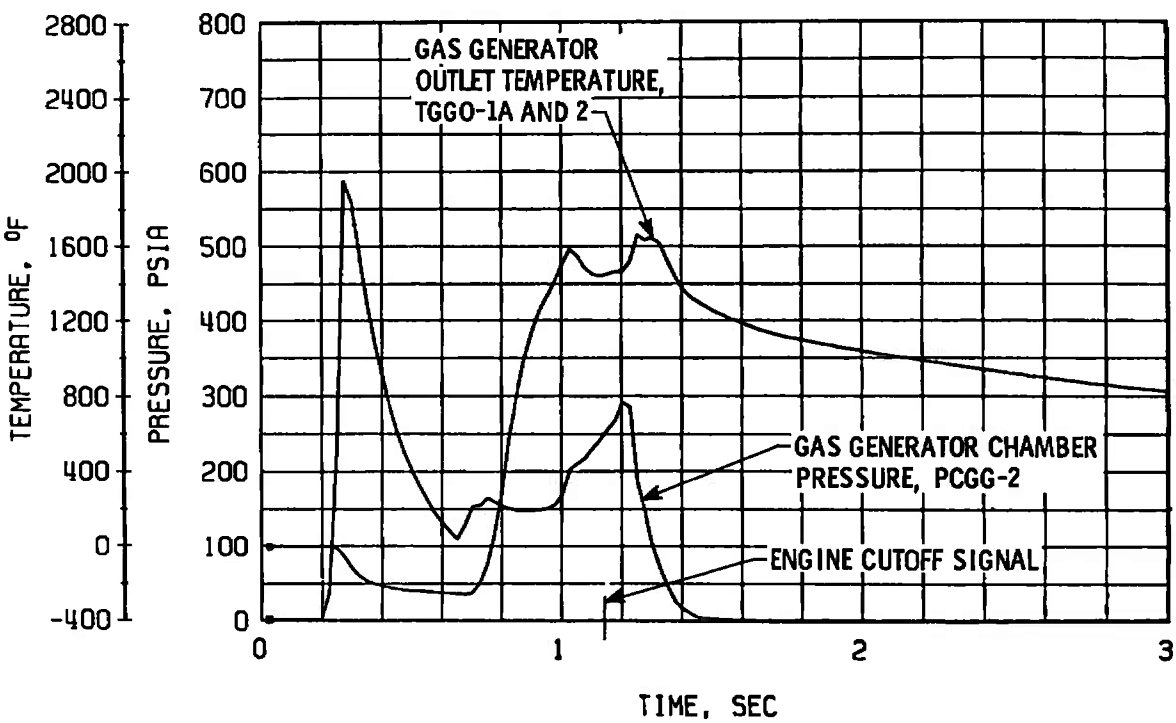


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 54 Engine Transient Operation, Firing 36E



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 54 Concluded

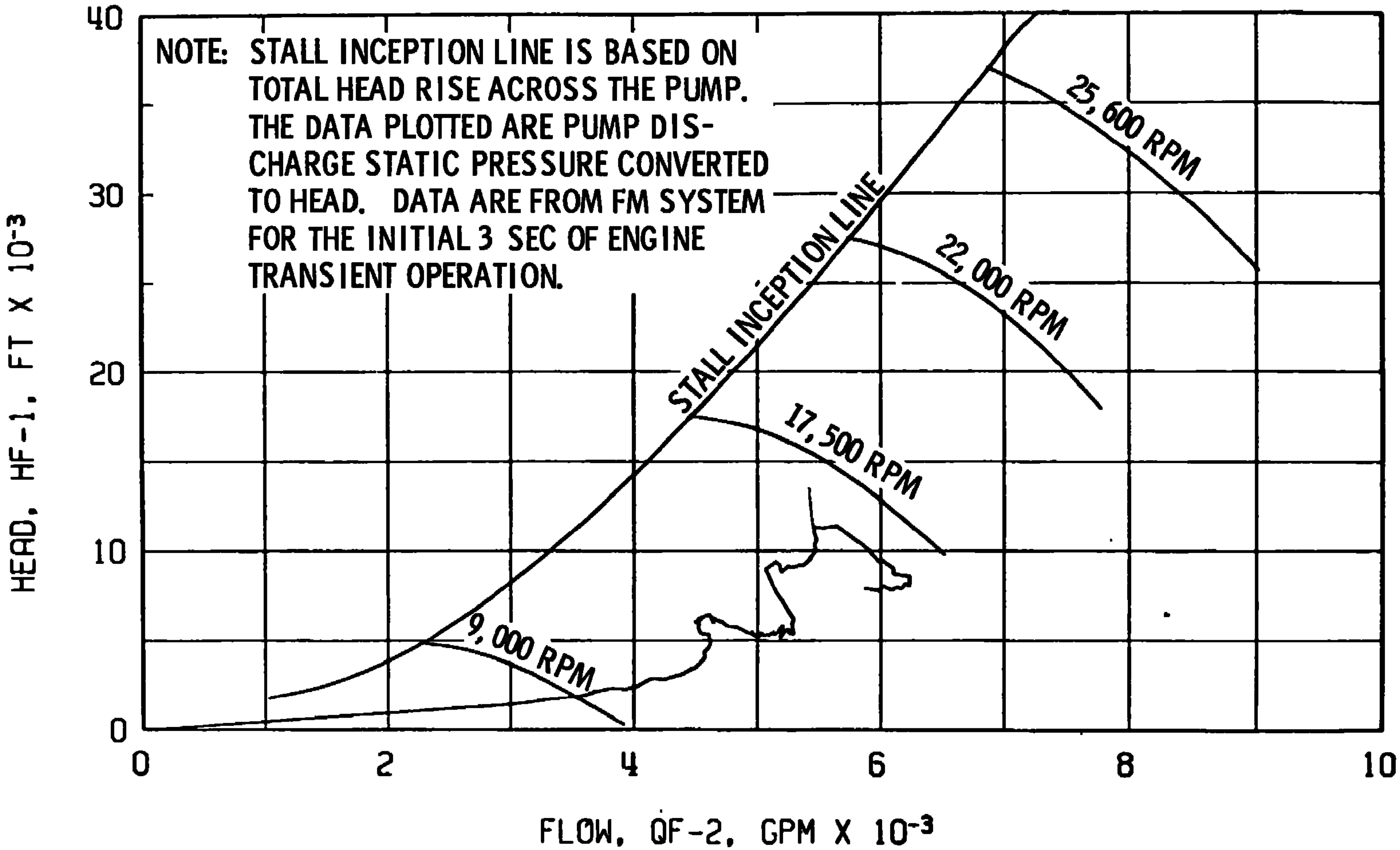


Fig. 55 Fuel Pump Start Transient Performance, Firing 36E

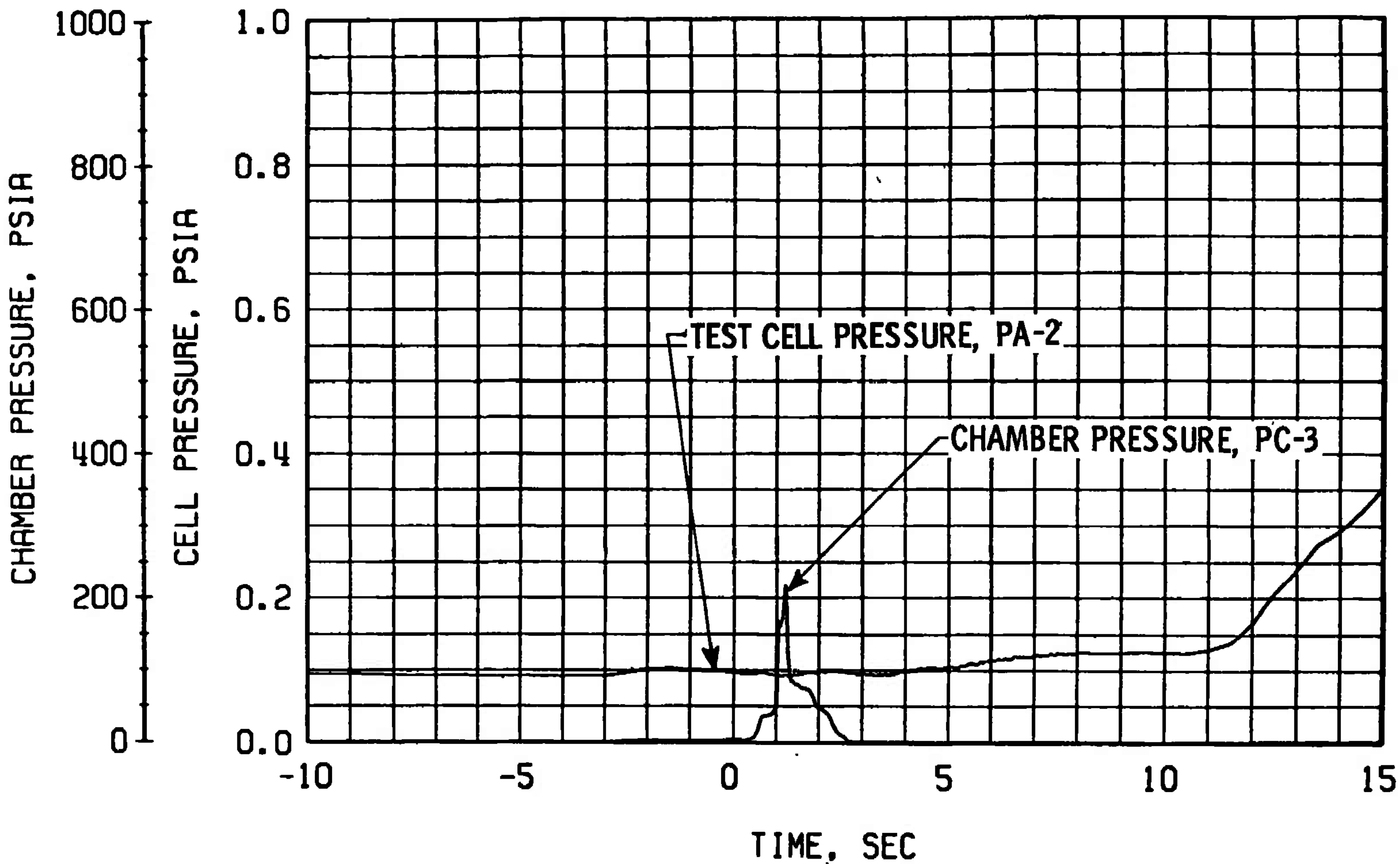
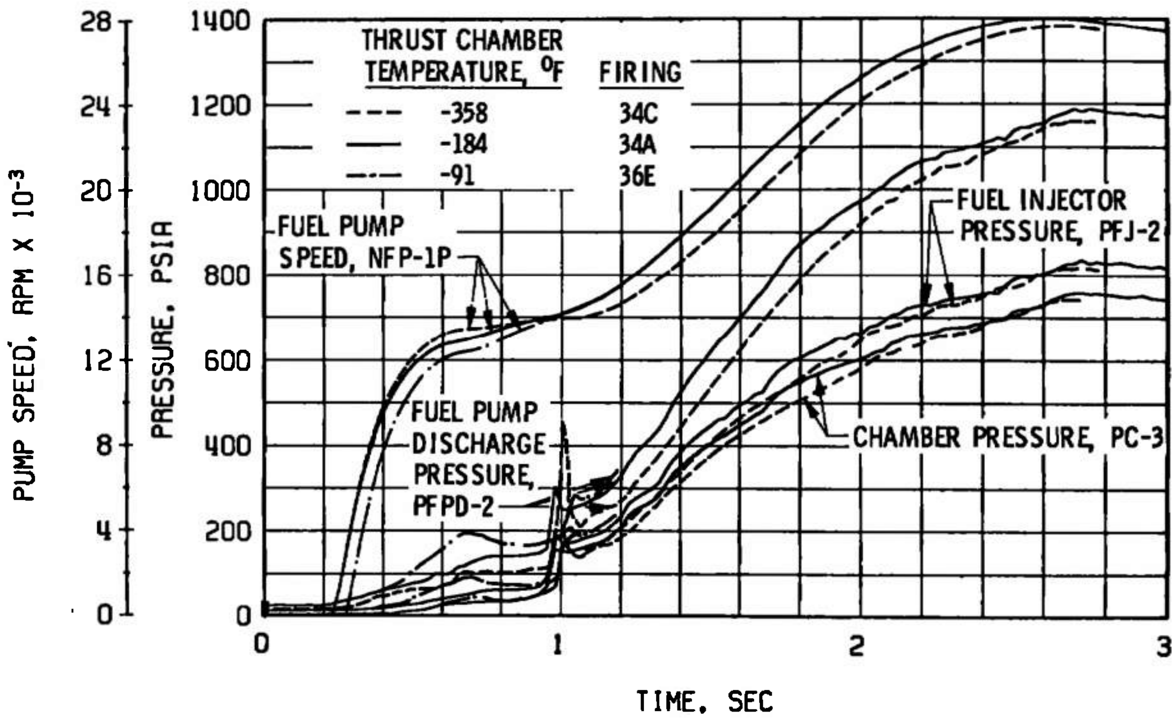
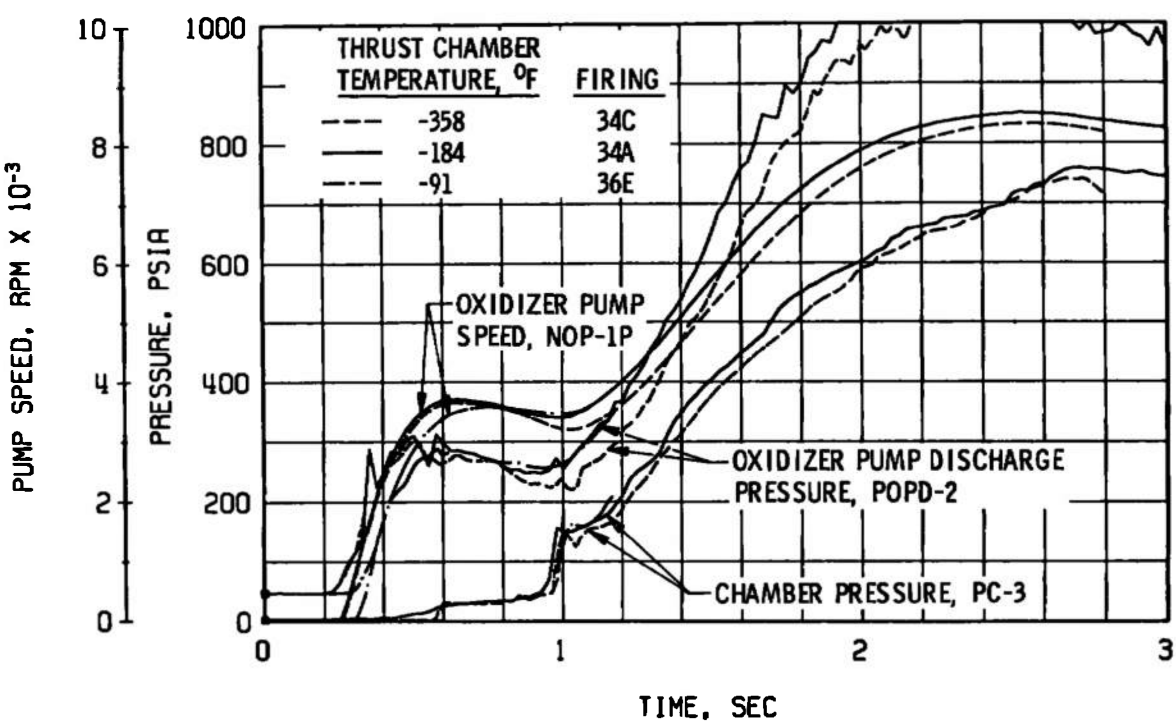


Fig. 56 Engine Ambient and Combustion Chamber Pressure, Firing 36E

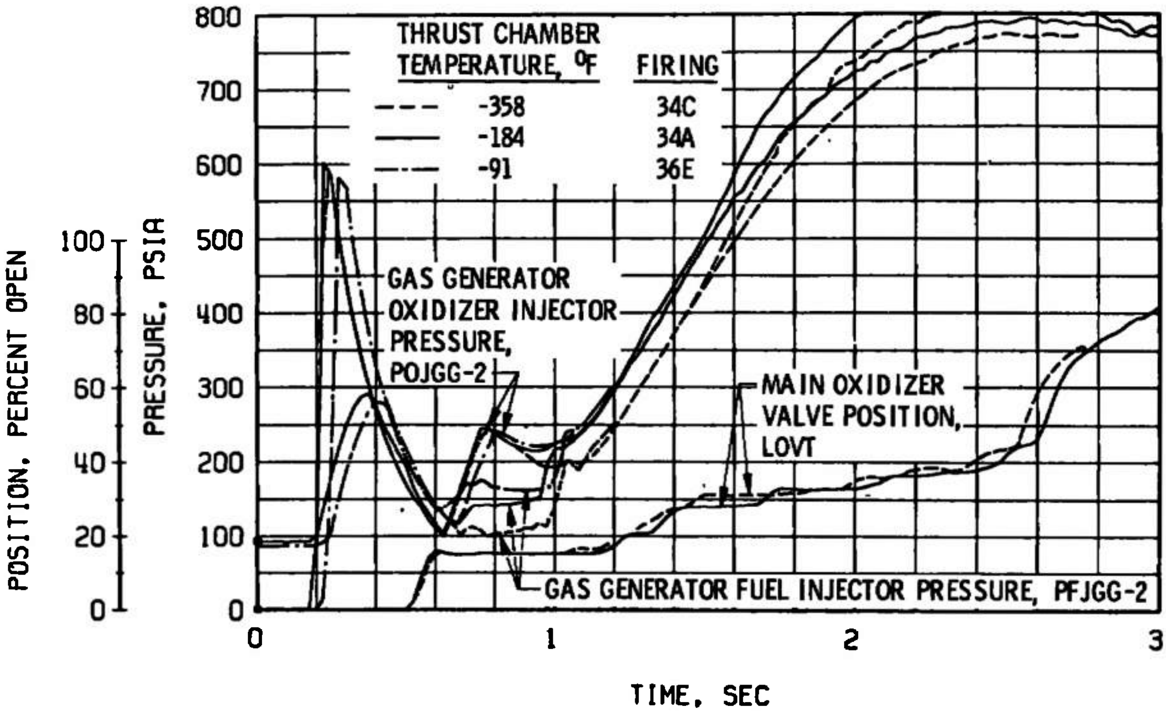


a. Thrust Chamber Fuel System

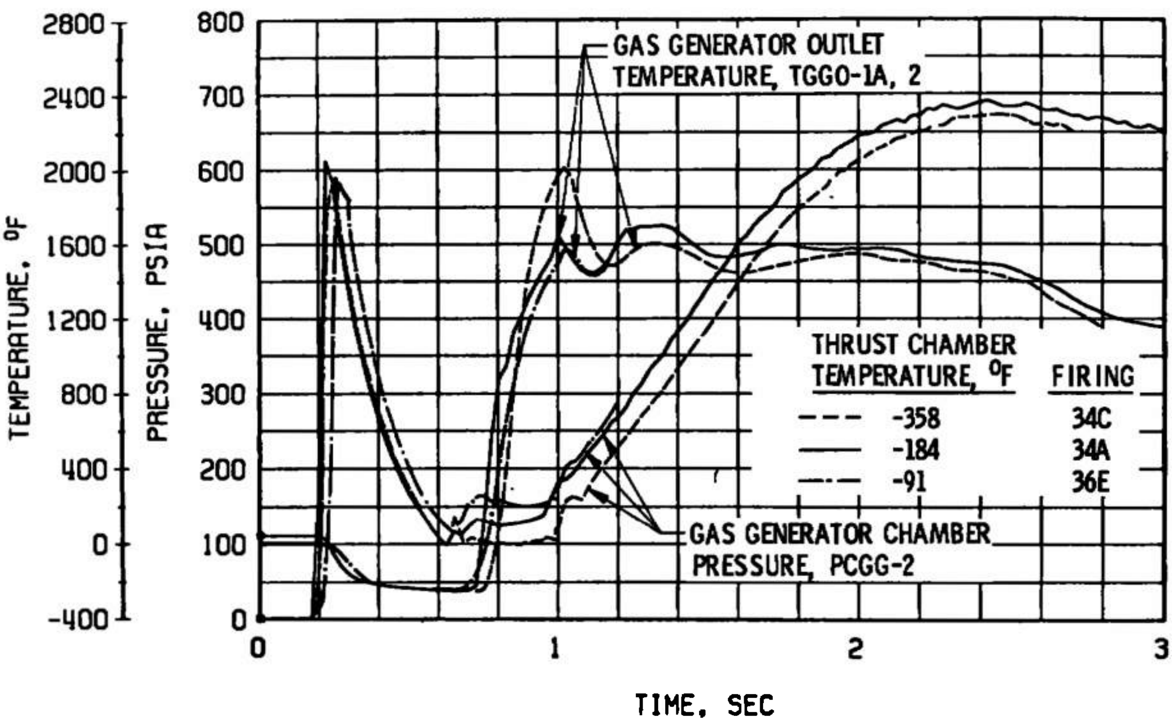


b. Thrust Chamber Oxidizer System

Fig. 57 Start Transient Comparison of Selected Engine Parameters, Firings 34A, 34C, and 36E



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position



d. Gas Generator Chamber Pressure and Outlet Temperature

Fig. 57 Concluded

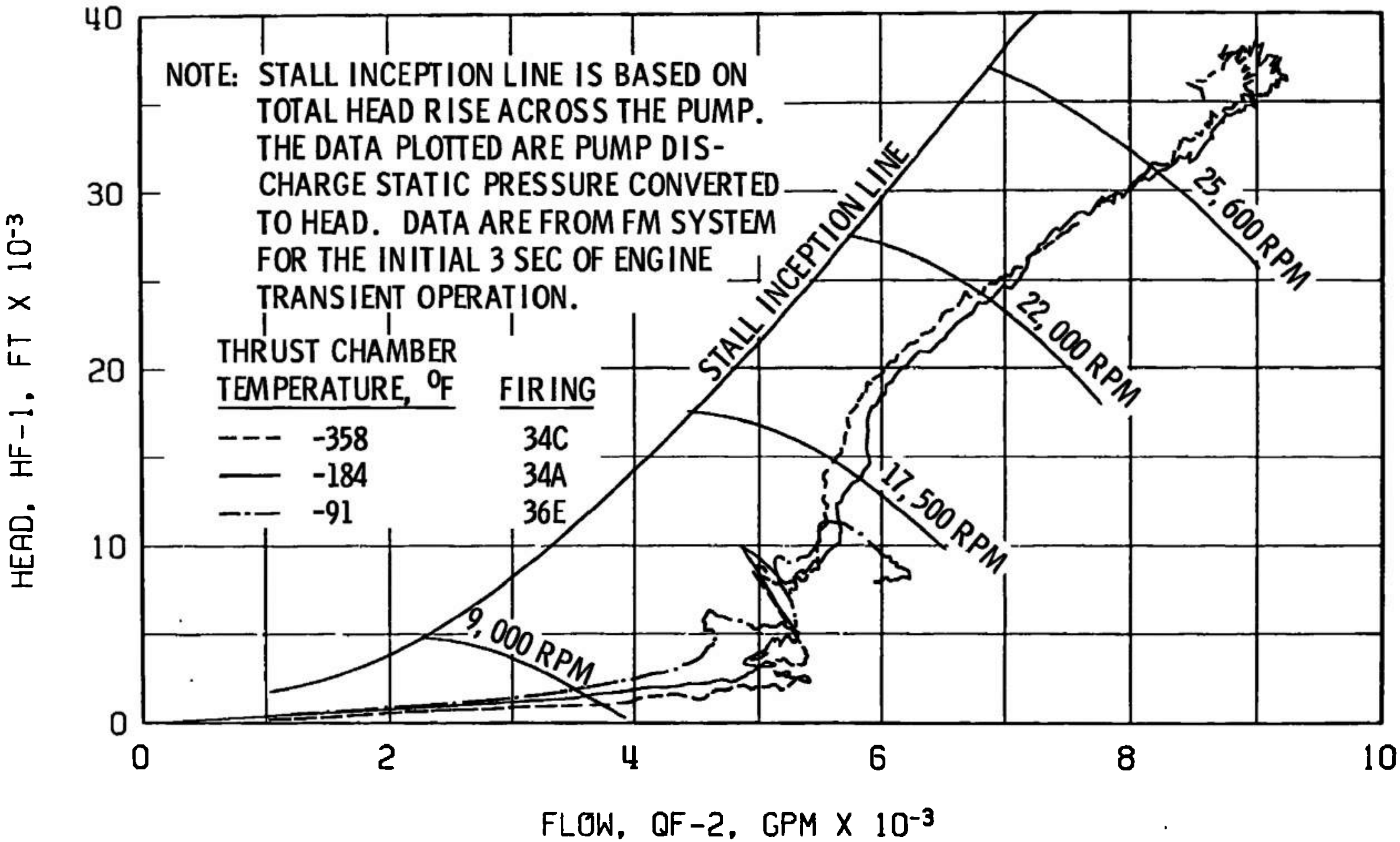
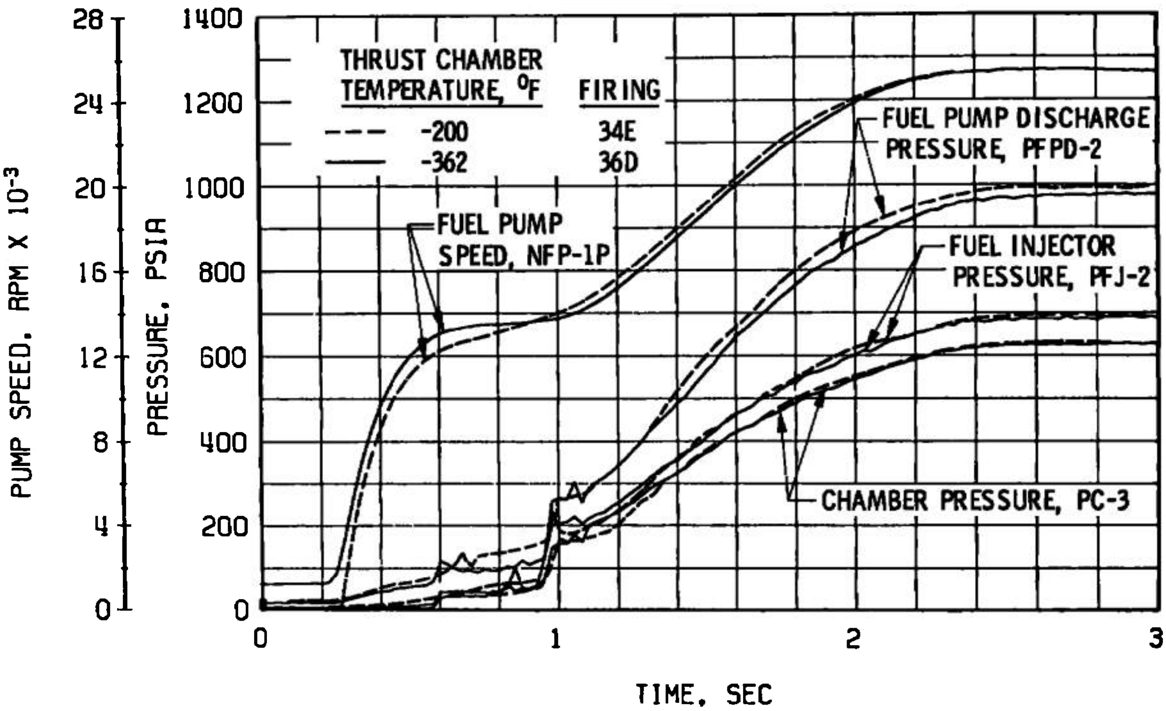
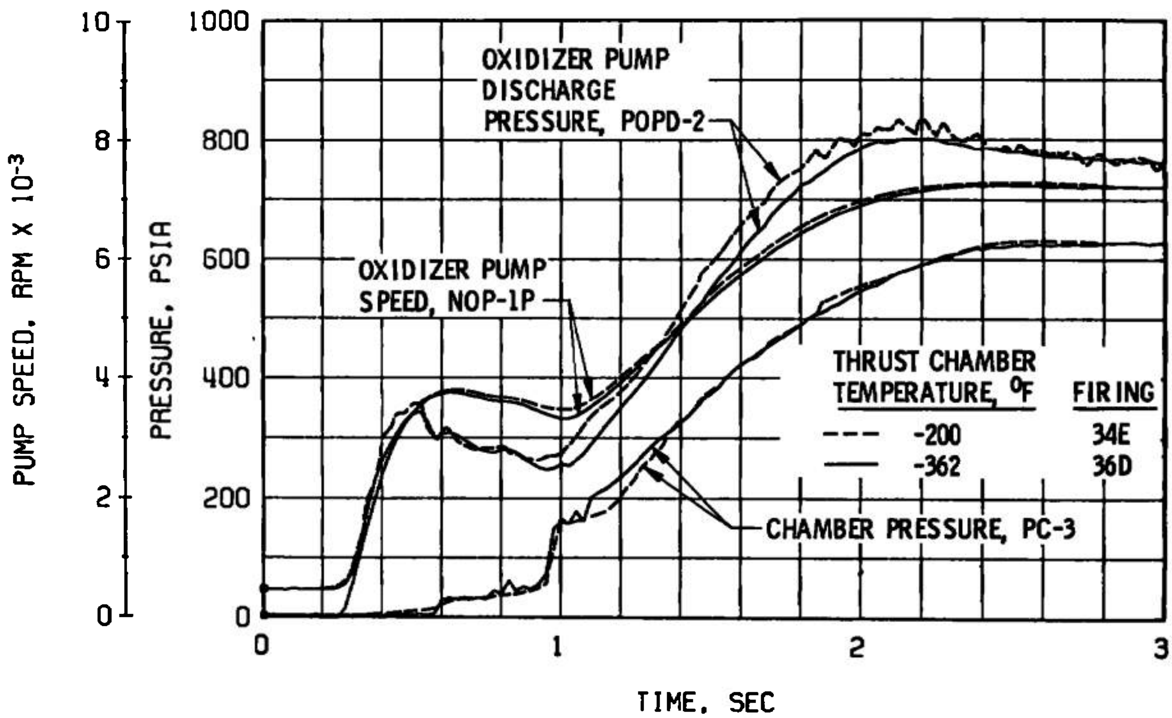


Fig. 58 Fuel Pump Start Transient Performance Comparison, Firings 34A, 34C, and 36E

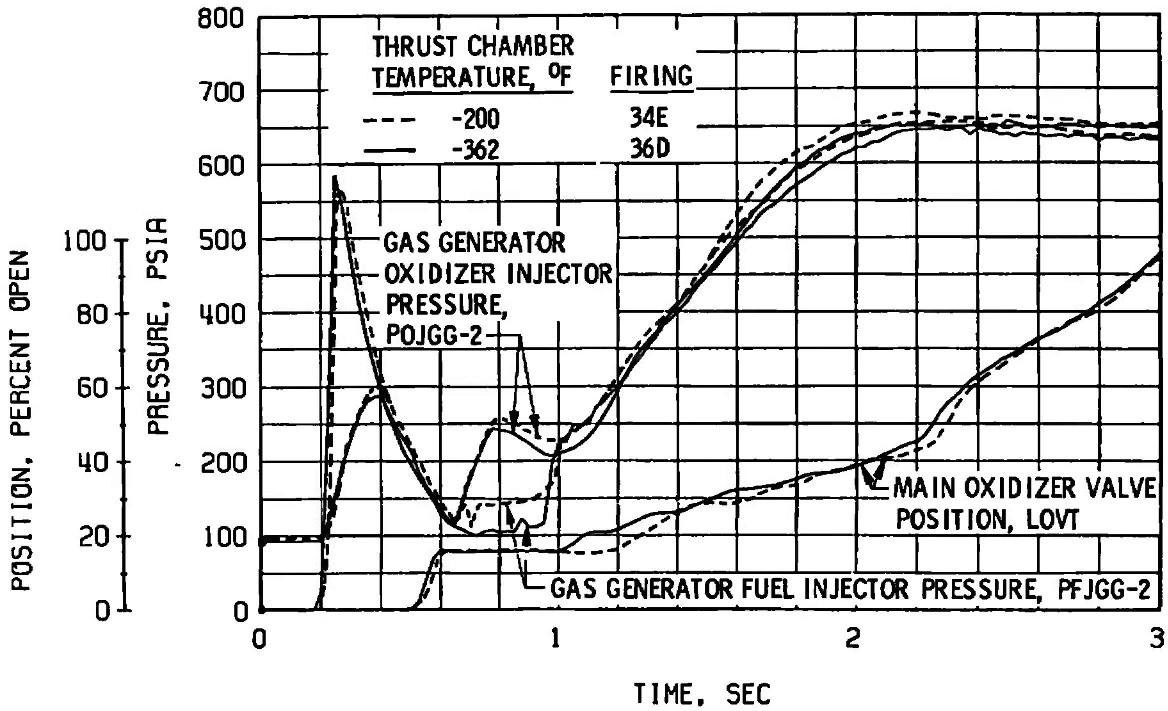


a. Thrust Chamber Fuel System

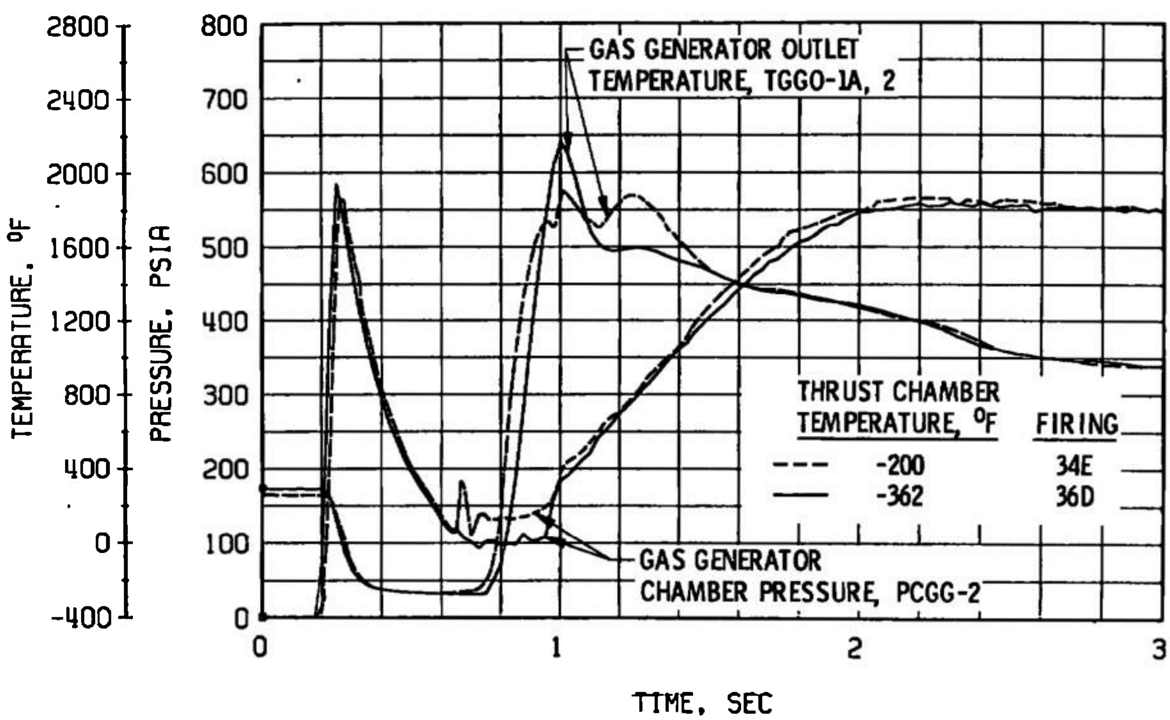


b. Thrust Chamber Oxidizer System

Fig. 59 Start Transient Comparison of Selected Engine Parameters, Firings 34E and 36D



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position



d. Gas Generator Chamber Pressure and Outlet Temperature
Fig. 59 Concluded

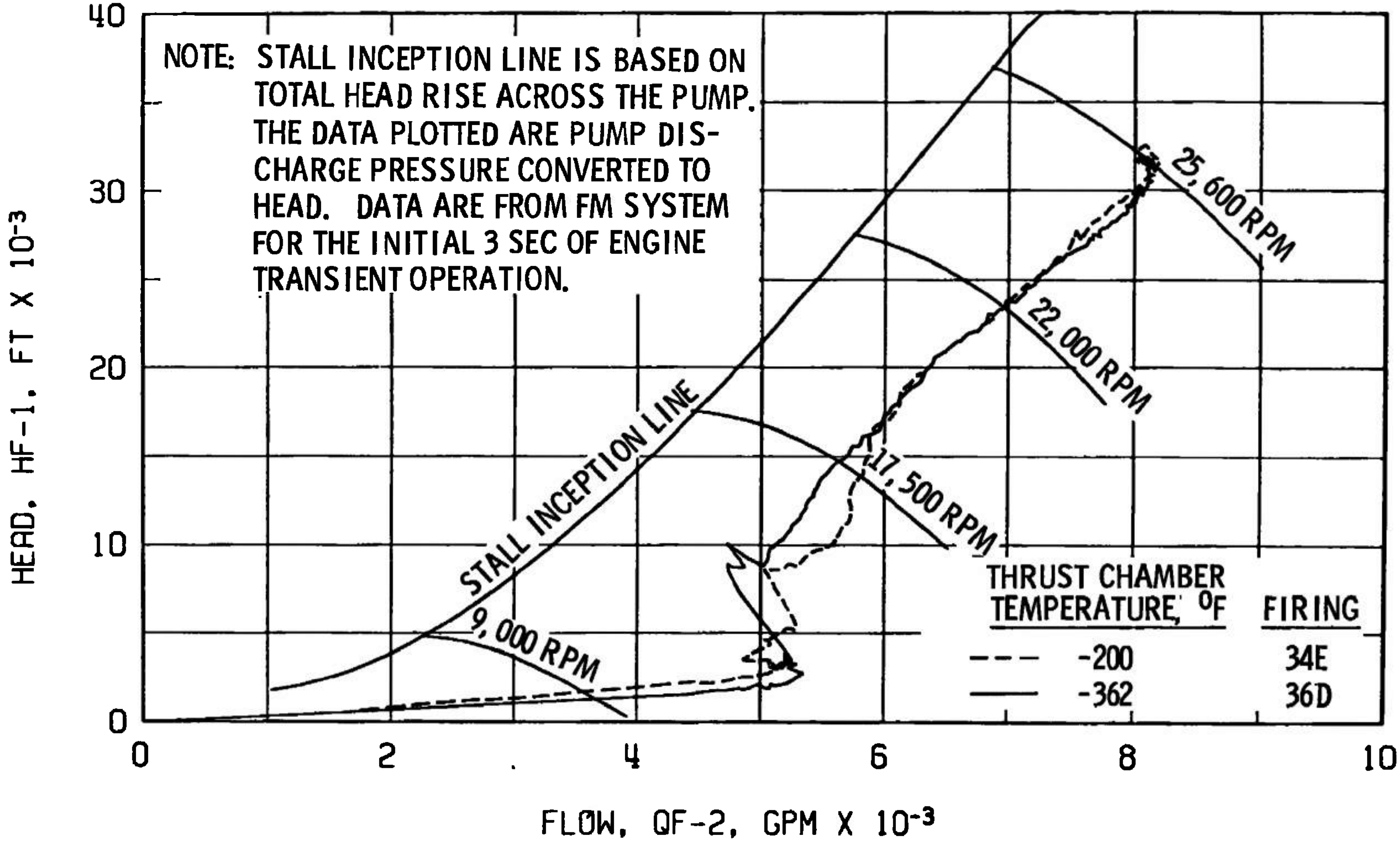
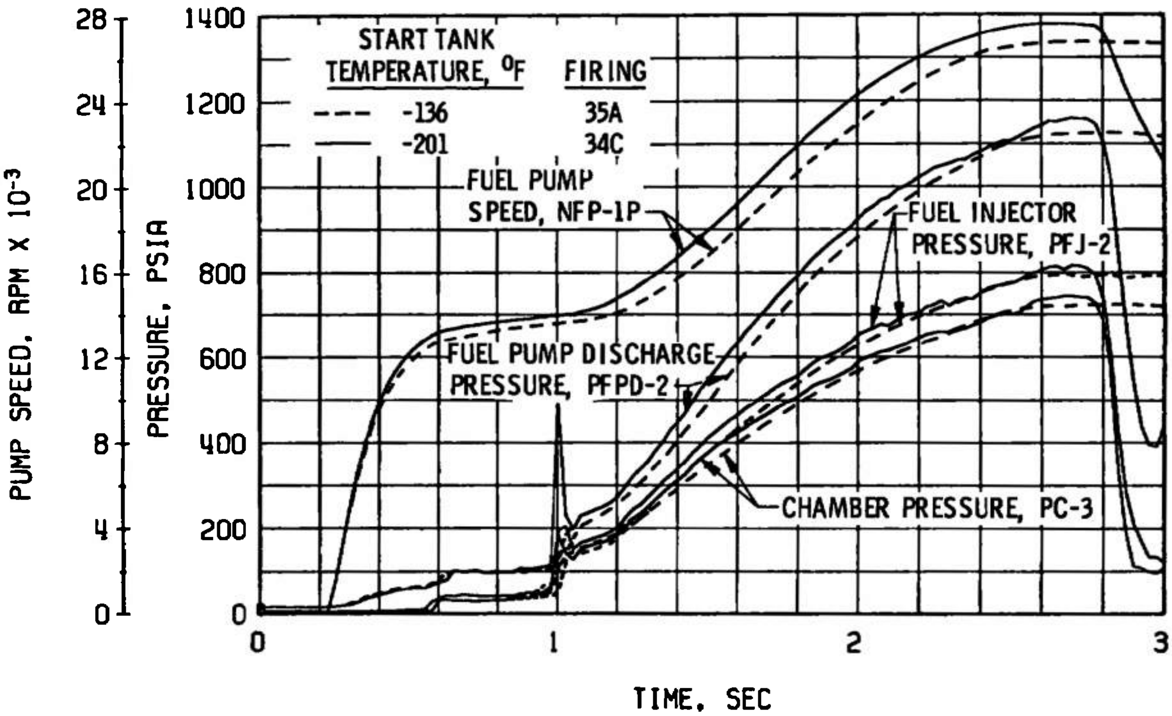
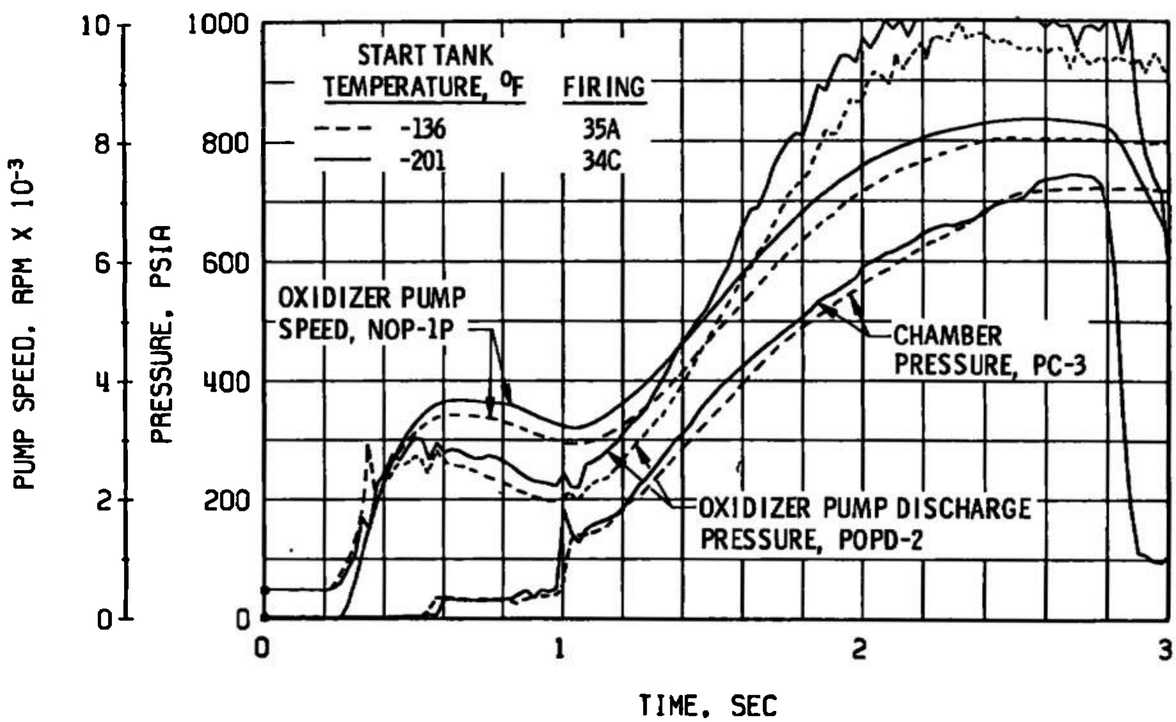


Fig. 60 Fuel Pump Start Transient Performance Comparison, Firings 34E and 36D

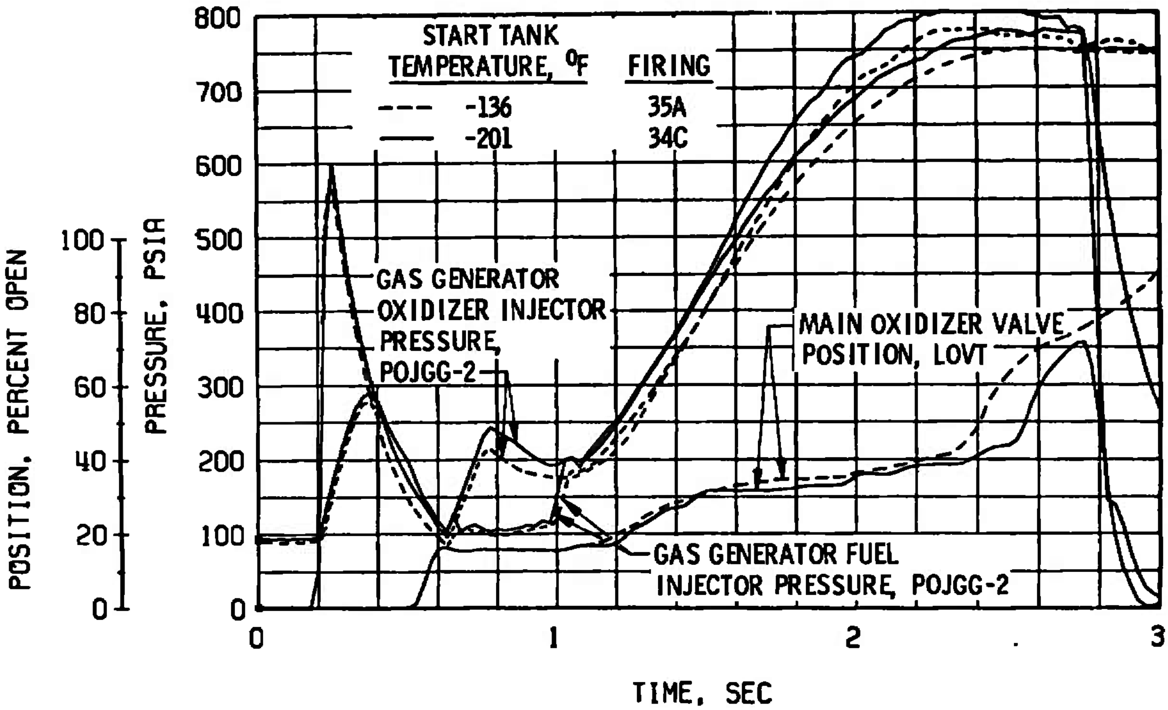


a. Thrust Chamber Fuel System

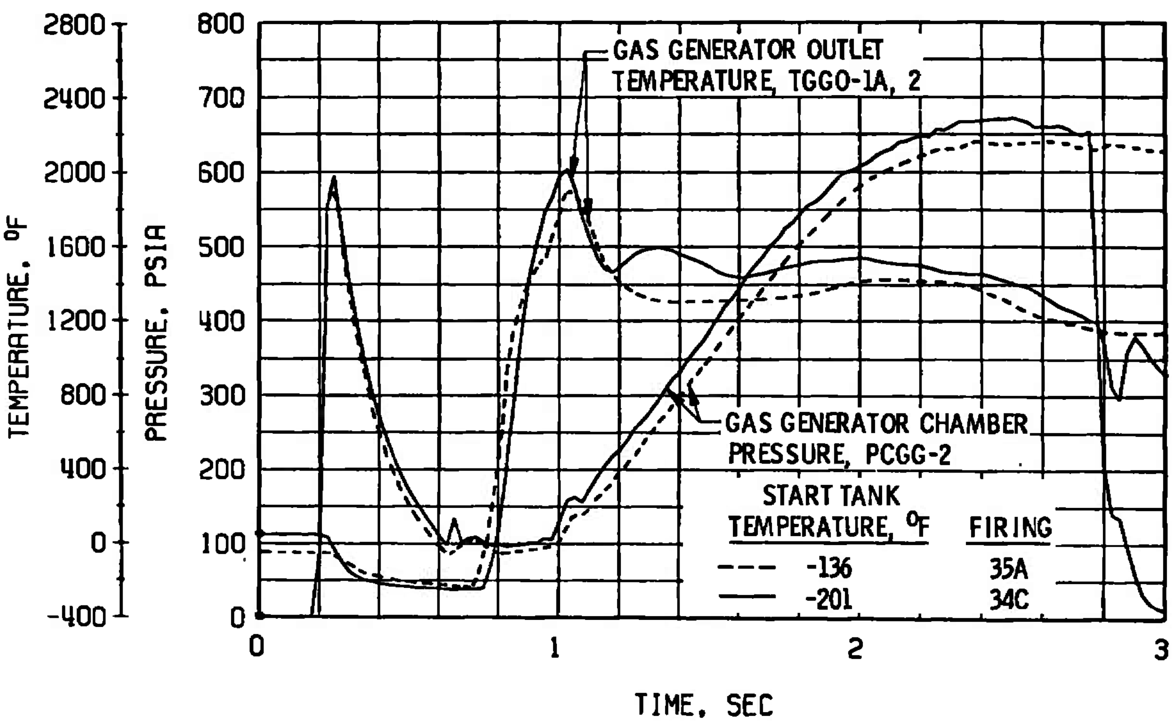


b. Thrust Chamber Oxidizer System

Fig. 61 Start Transient Comparison of Selected Engine Parameters, Firings 34C and 35A



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position



d. Gas Generator Chamber Pressure and Outlet Temperature

Fig. 61 Concluded

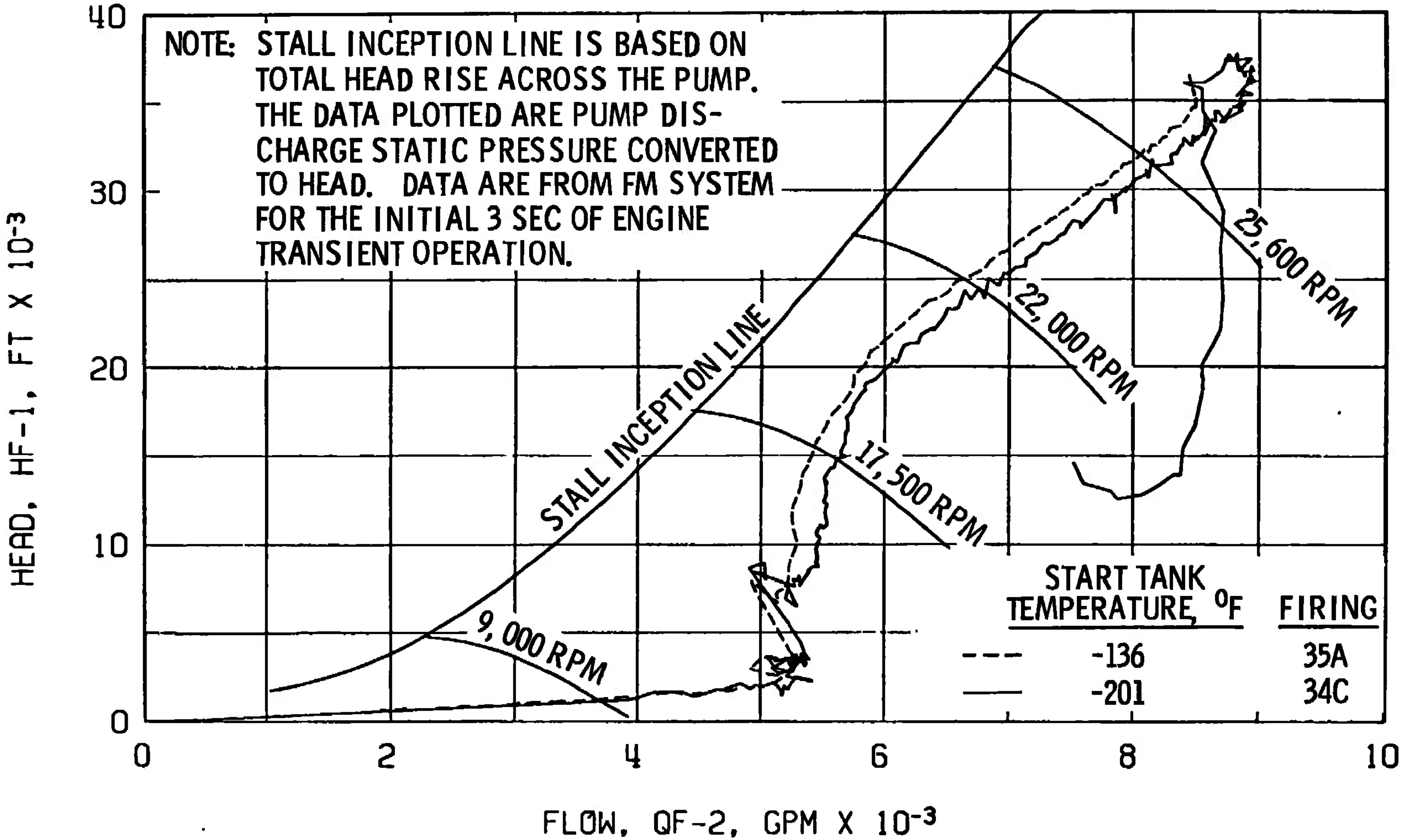
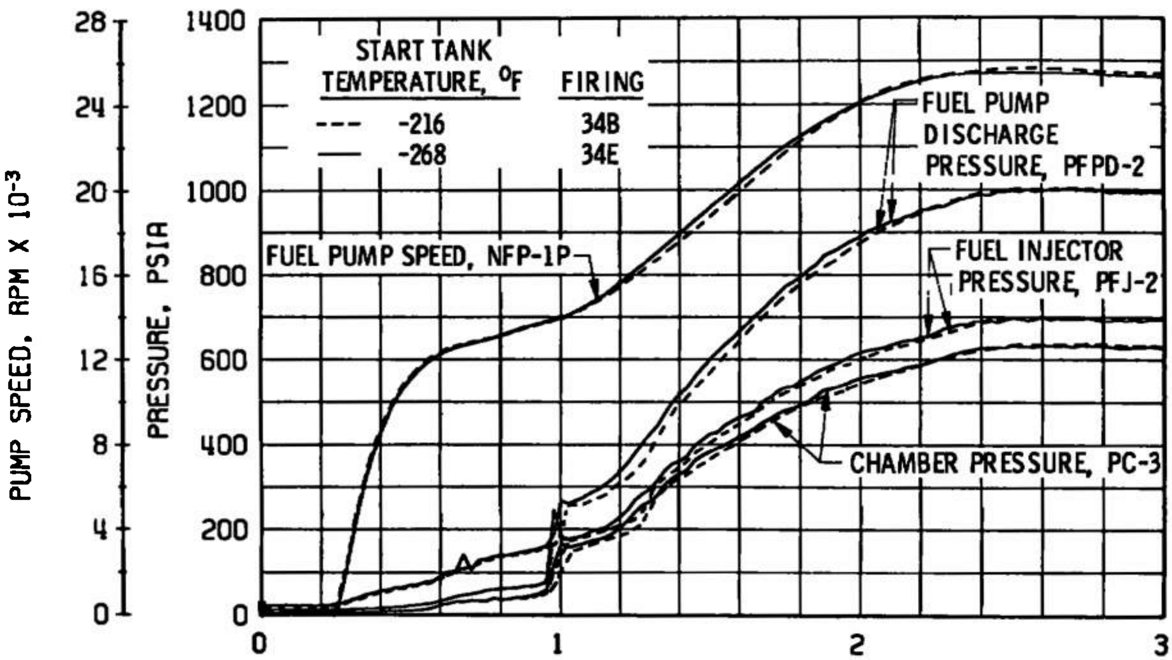
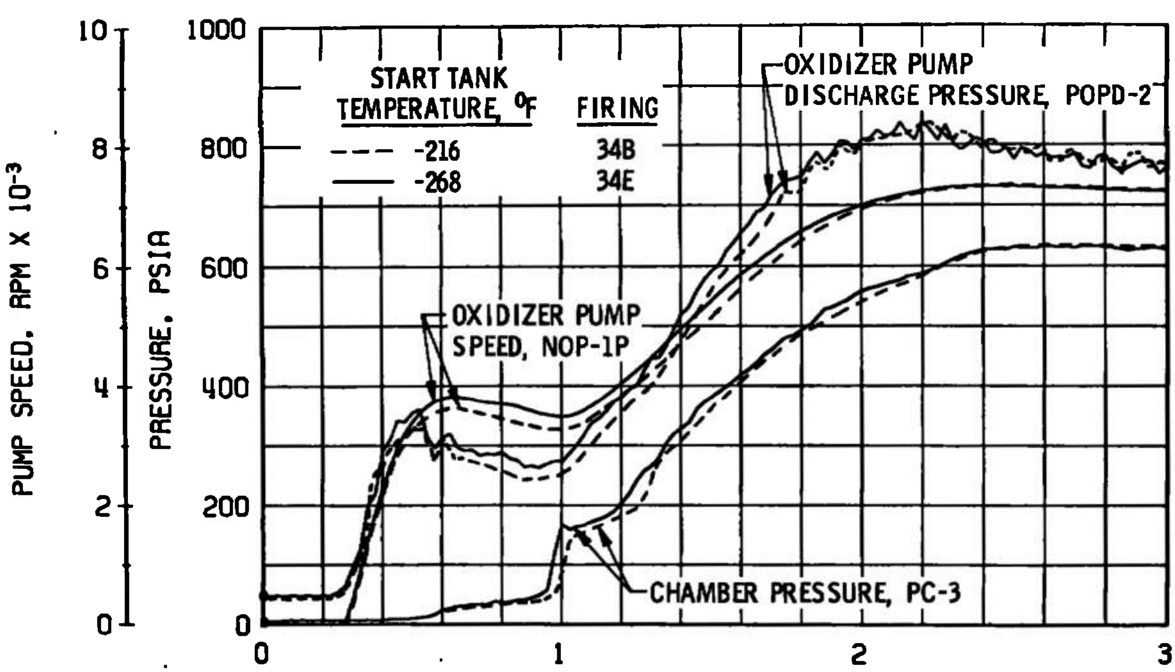


Fig. 62 Fuel Pump Start Transient Performance Comparison, Firings 34C and 35A

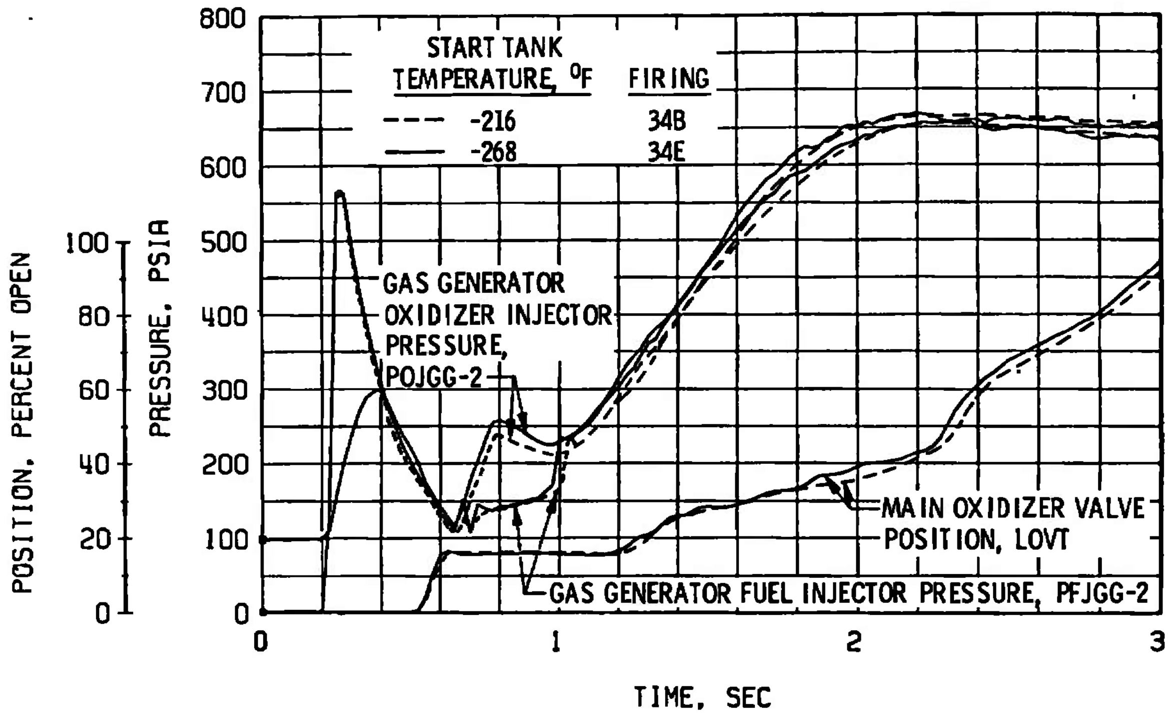


a. Thrust Chamber Fuel System

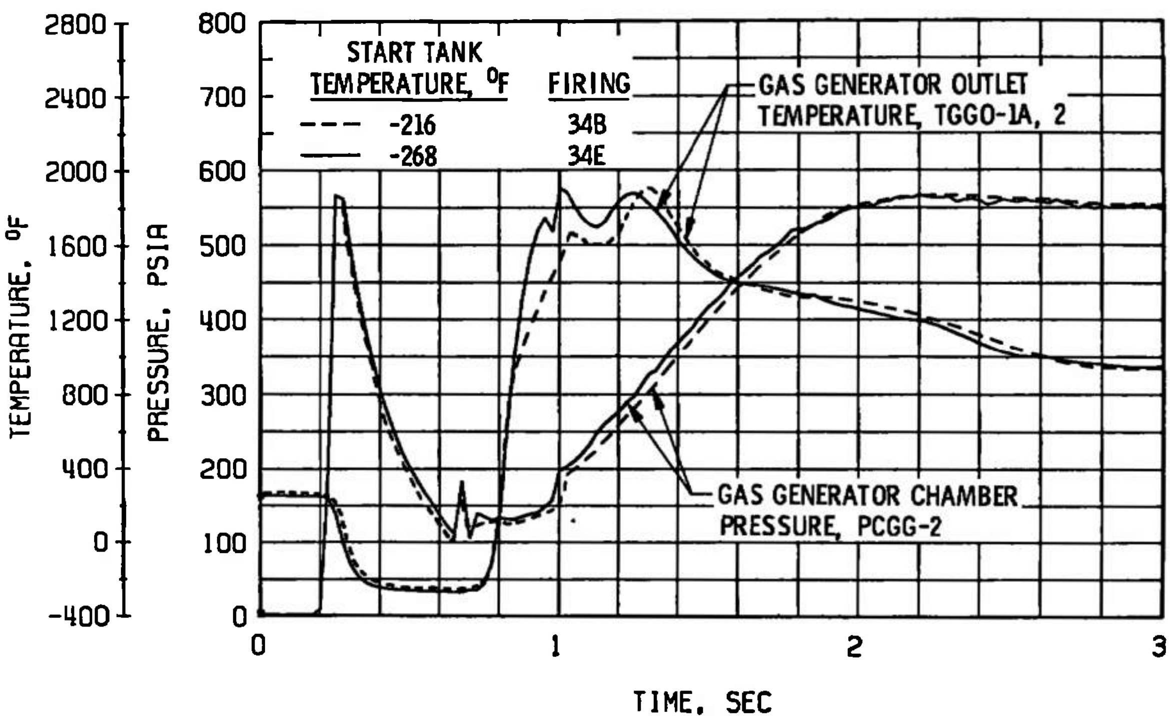


b. Thrust Chamber Oxidizer System

Fig. 63 Start Transient Comparison of Selected Engine Parameters, Firings 34B and 34E



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position



d. Gas Generator Chamber Pressure and Outlet Temperature

Fig. 63 Concluded

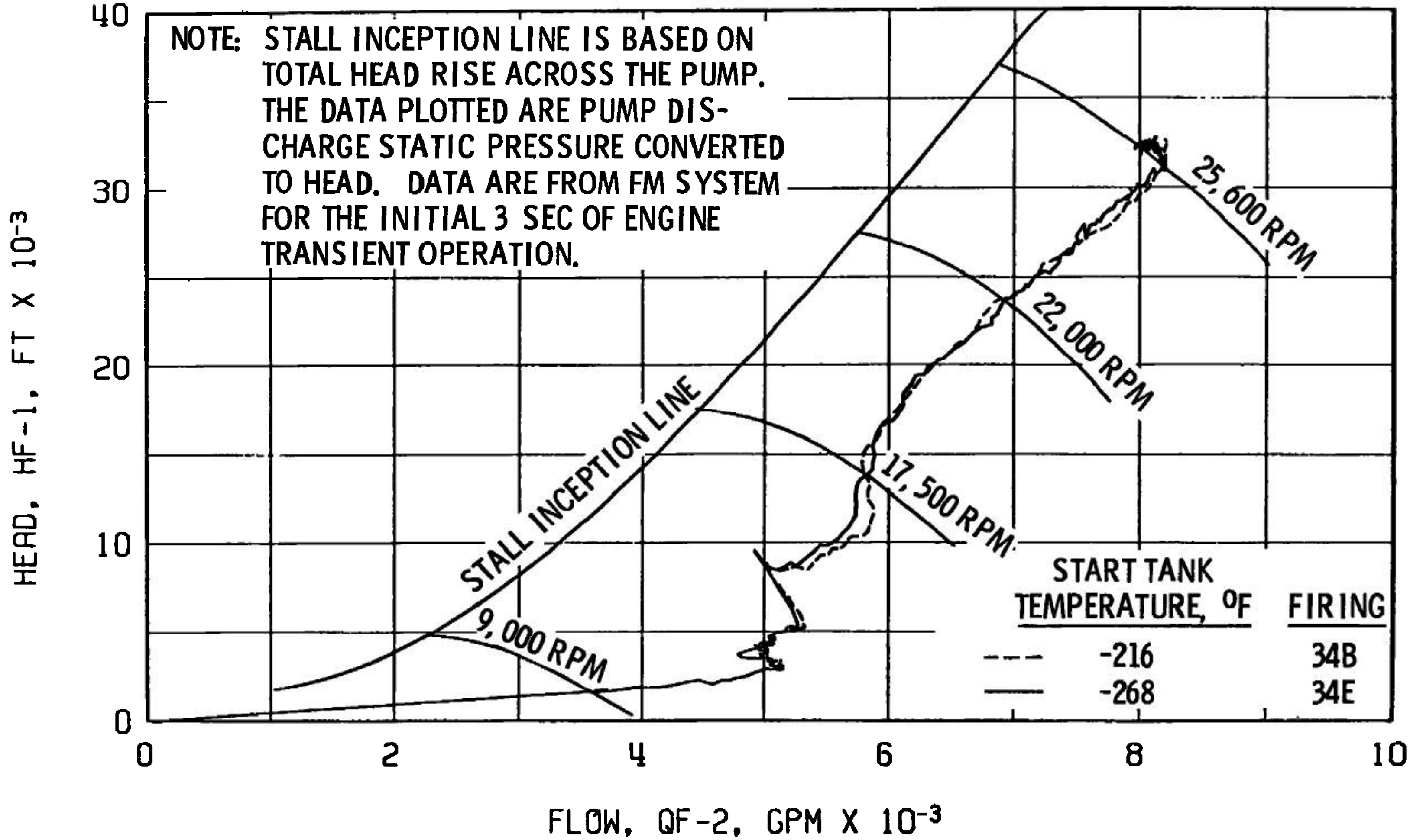
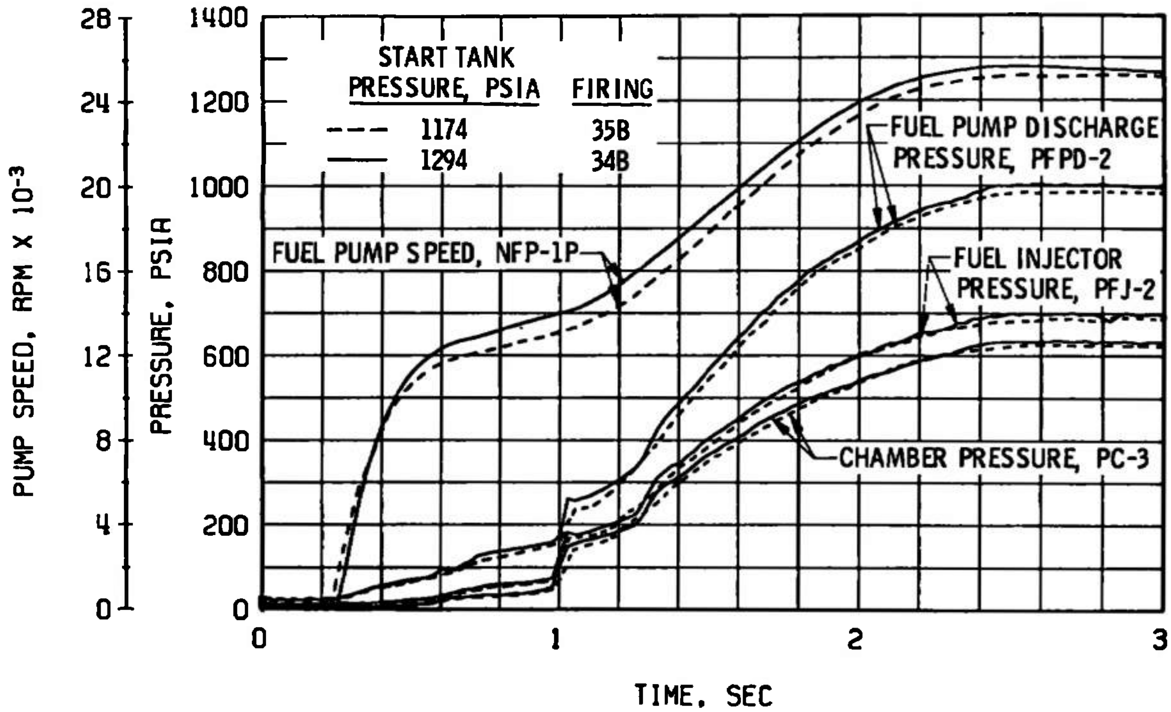
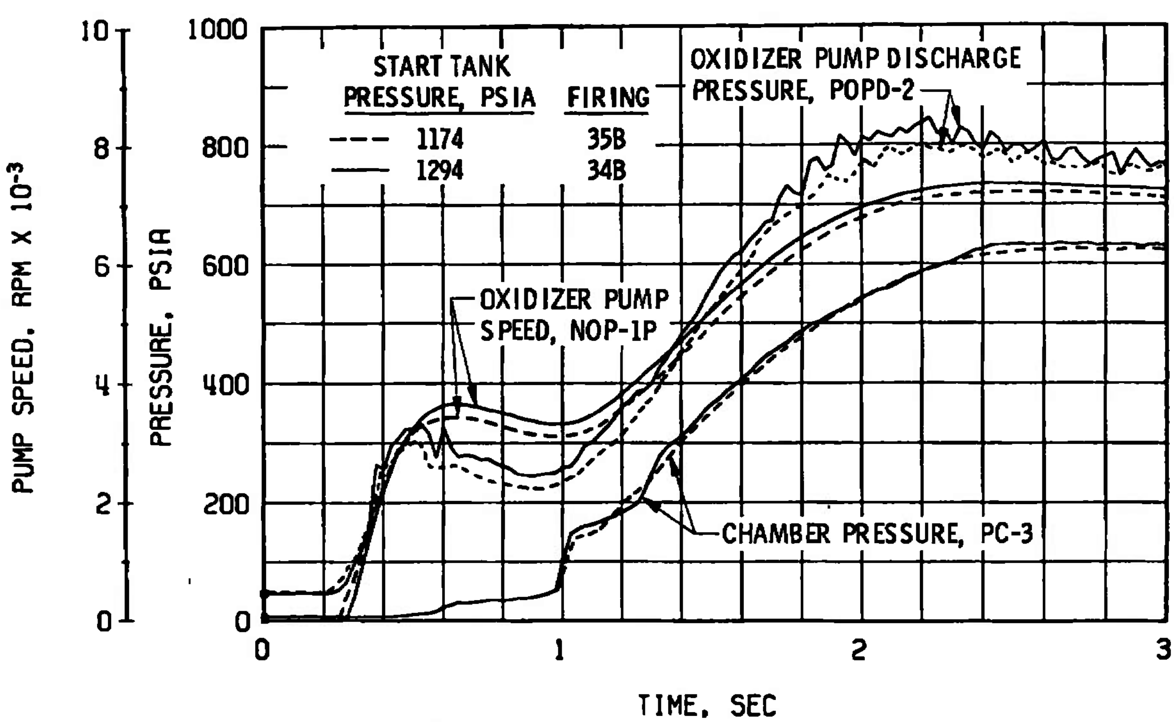


Fig. 64 Fuel Pump Start Transient Performance Comparison, Firings 34B and 34E

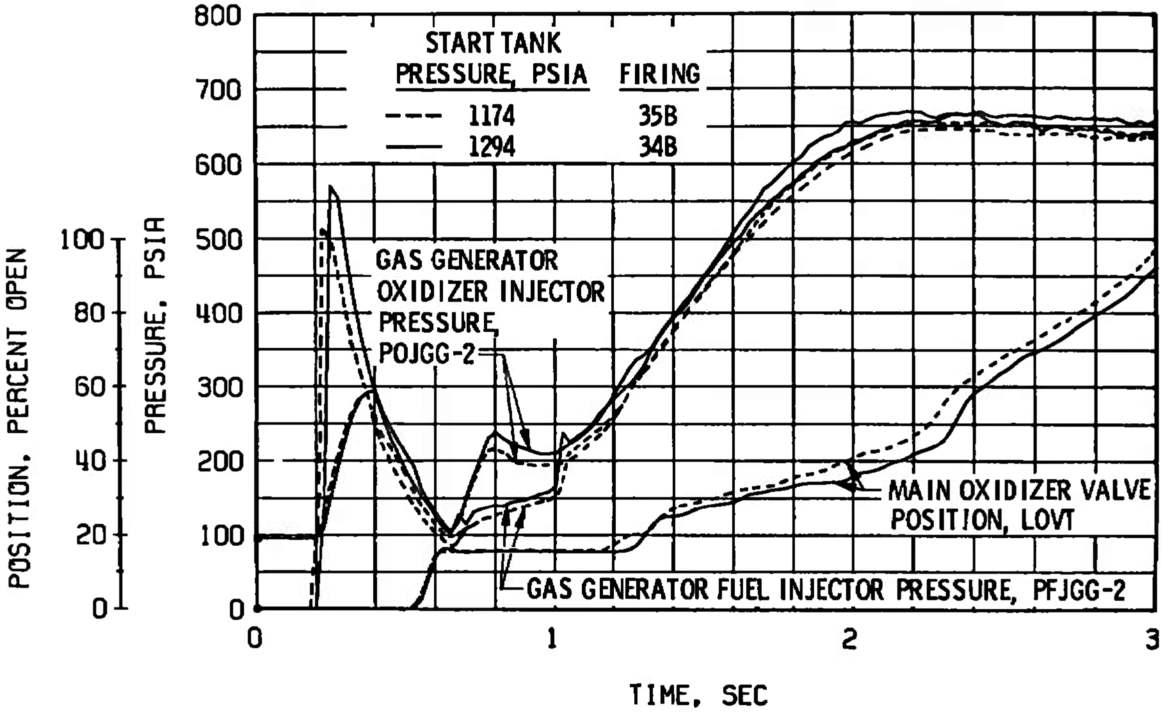


a. Thrust Chamber Fuel System

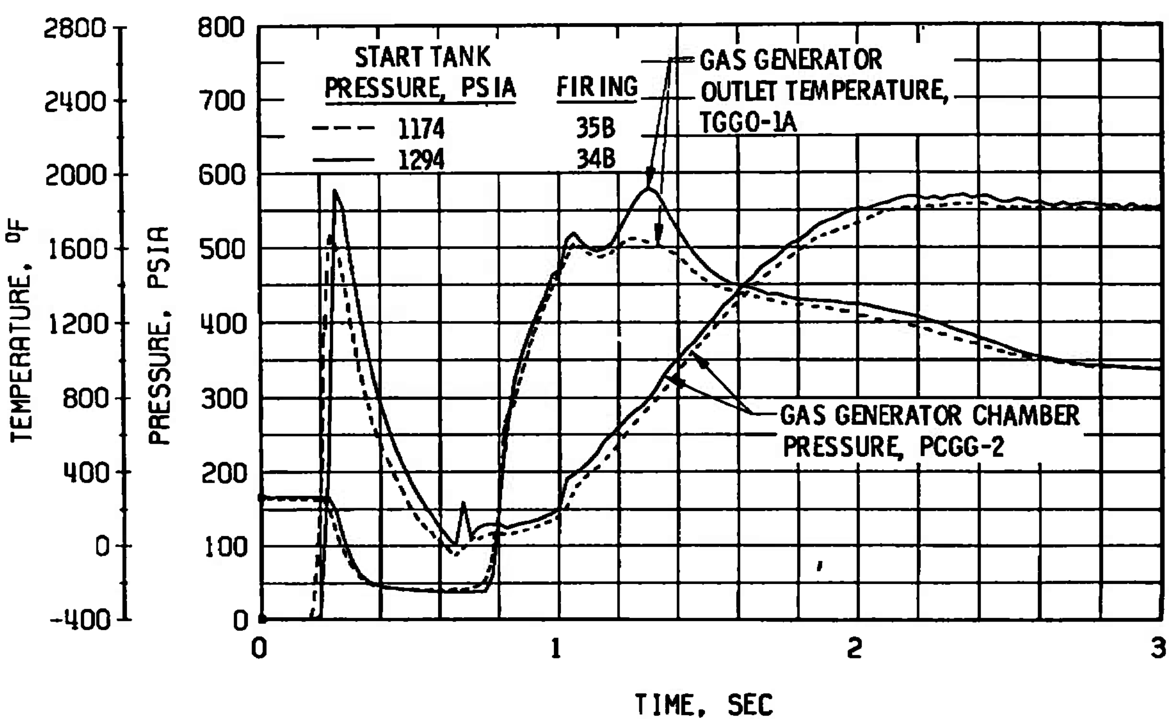


b. Thrust Chamber Oxidizer System

Fig. 65 Start Transient Comparison of Selected Engine Parameters, Firings 34B and 35B



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position



d. Gas Generator Chamber Pressure and Outlet Temperature

Fig. 65 Concluded

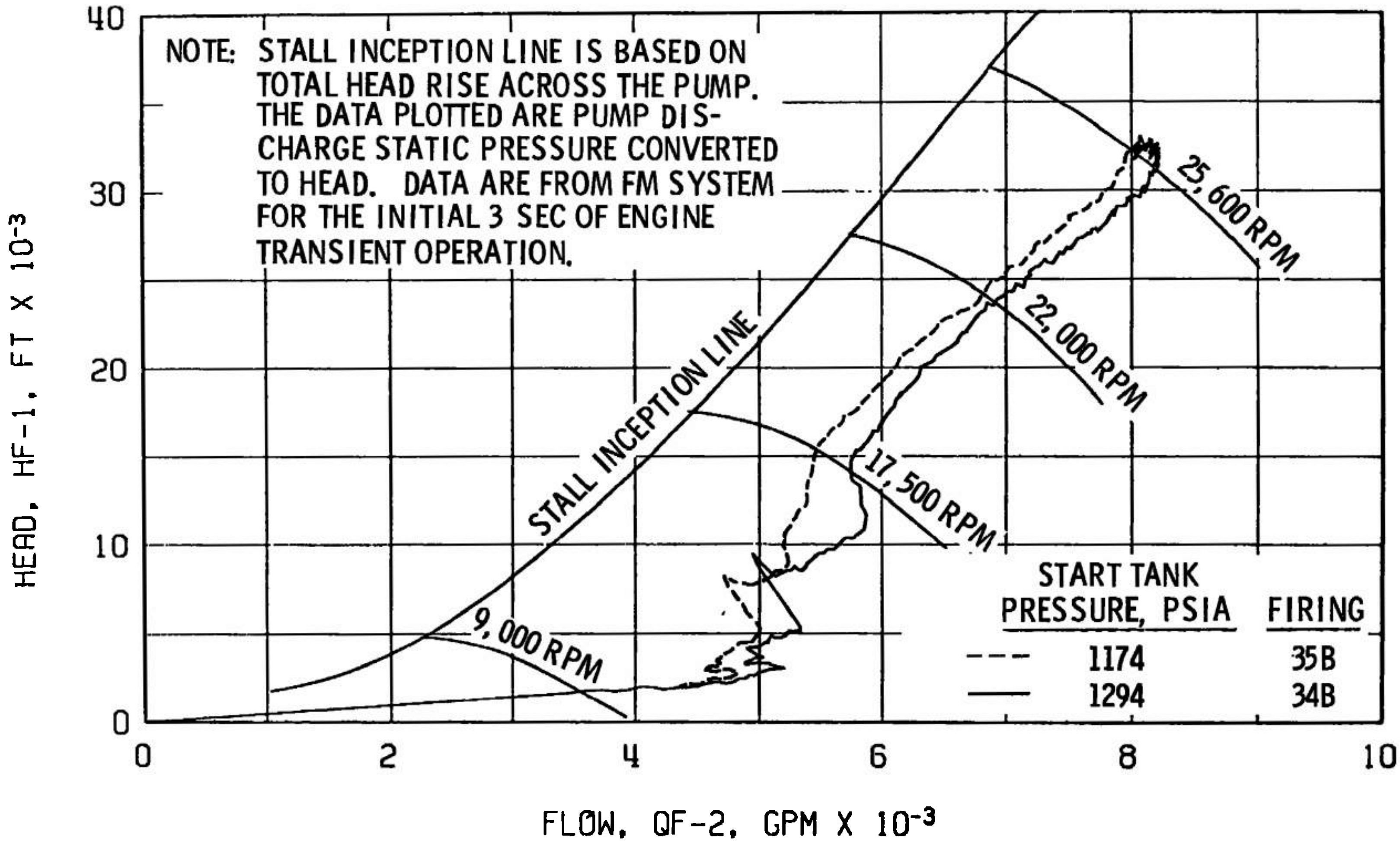
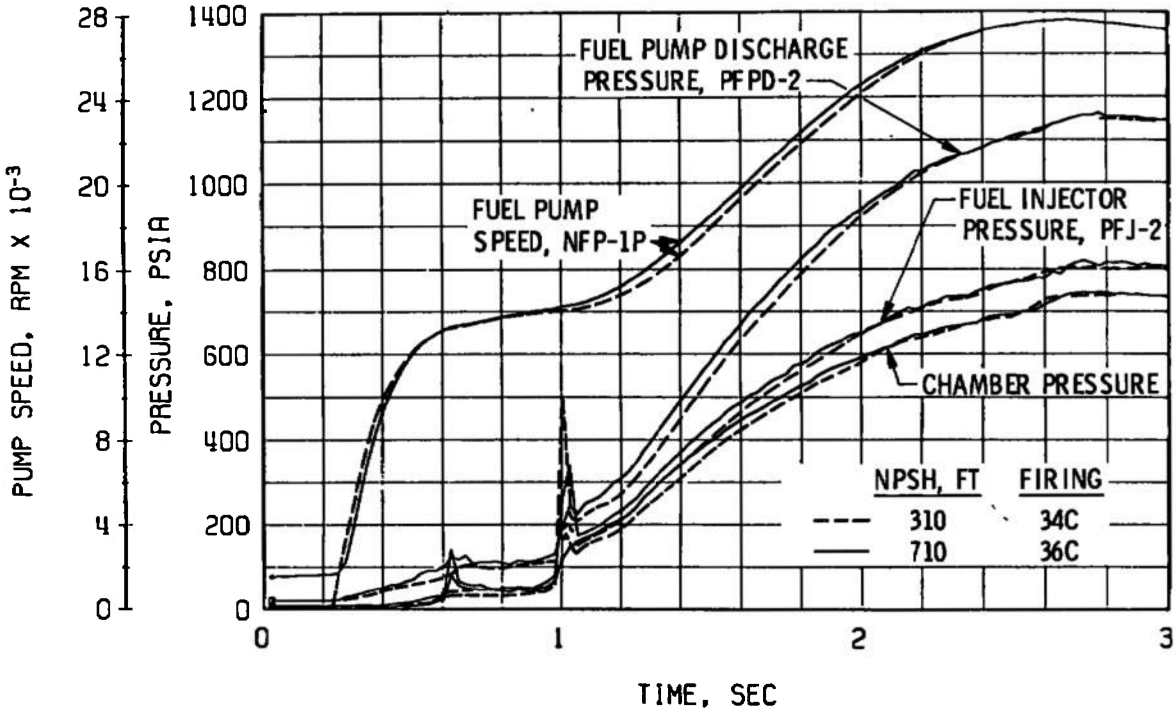
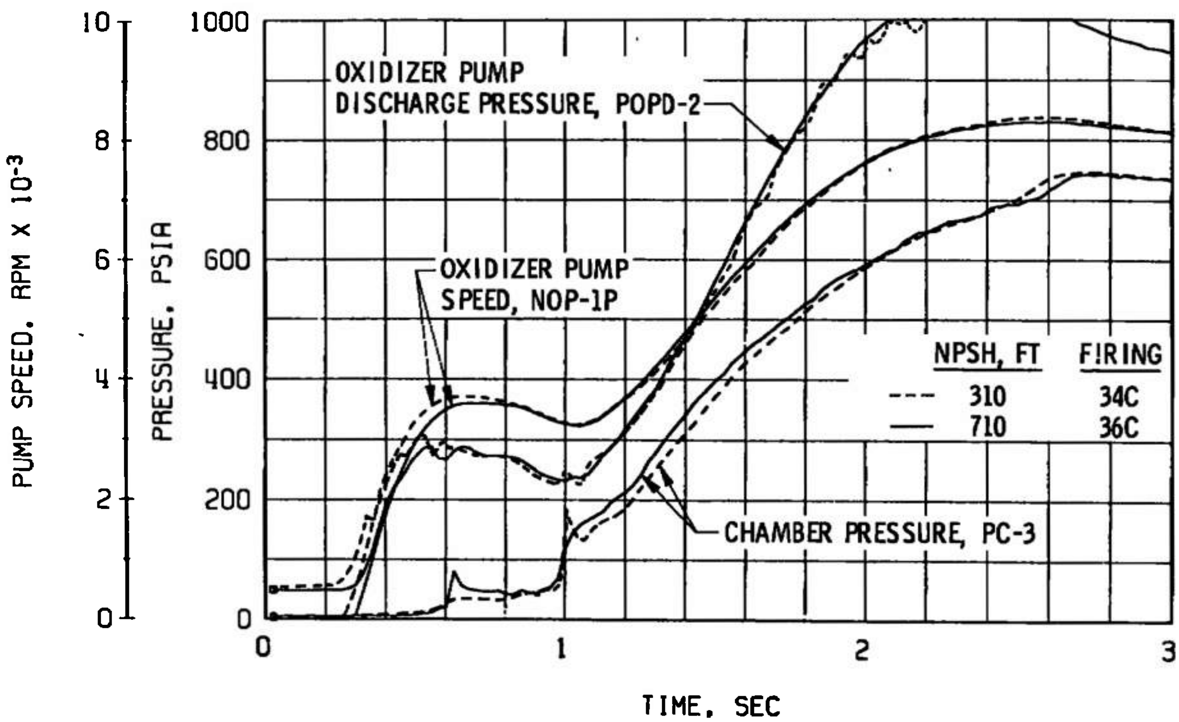


Fig. 66 Fuel Pump Start Transient Performance Comparison, Firings 34B and 35B

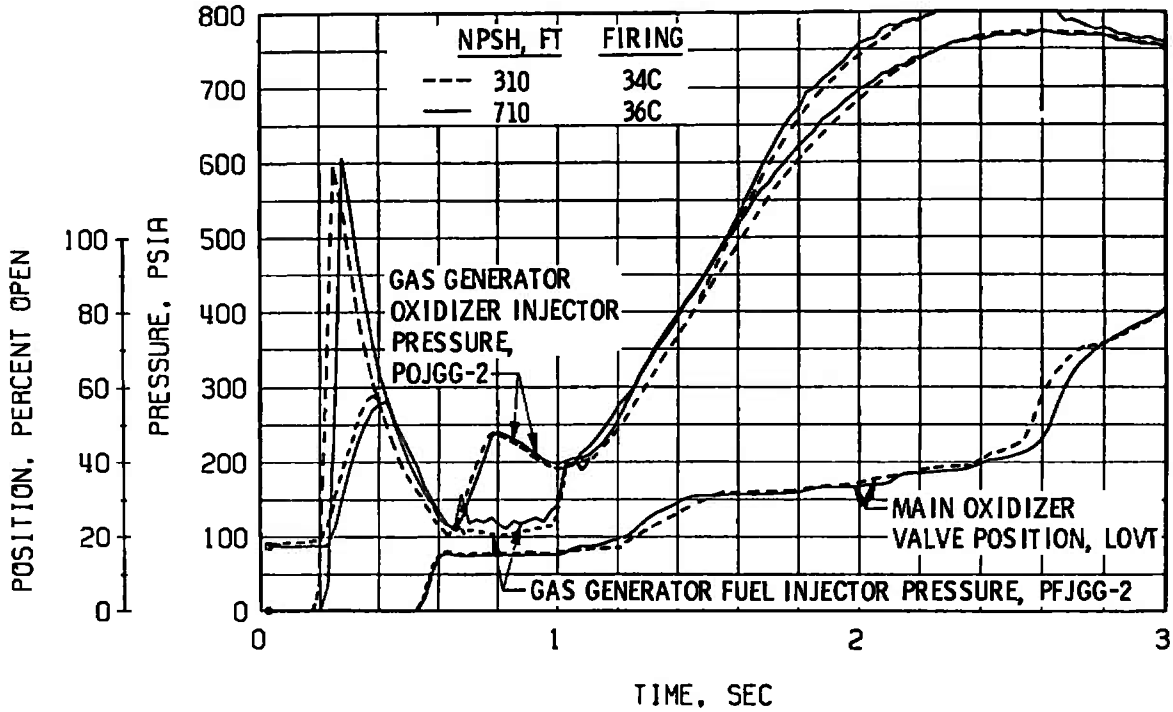


a. Thrust Chamber Fuel System

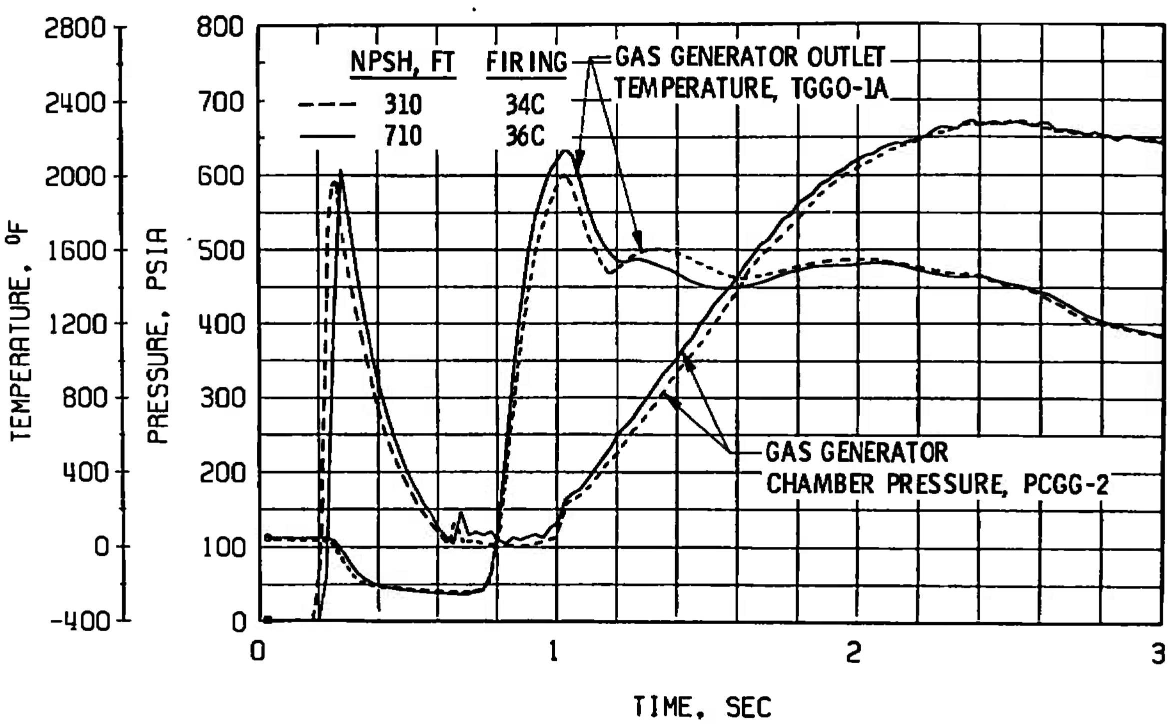


b. Thrust Chamber Oxidizer System

Fig. 67 Start Transient Comparison of Selected Engine Parameters, Firing 34C and 36C

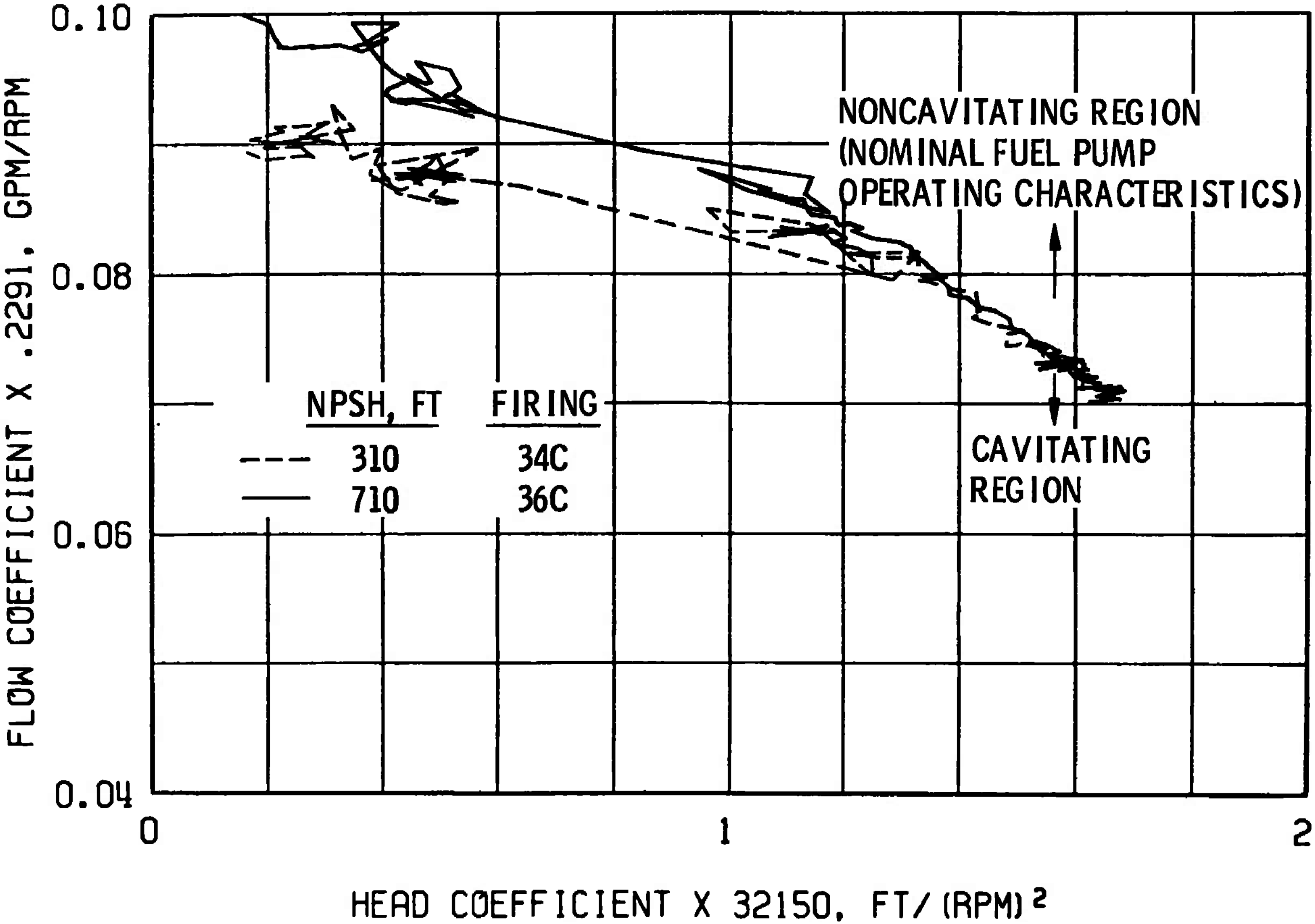


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position



d. Gas Generator Chamber Pressure and Outlet Temperature

Fig. 67 Continued



e. Fuel Pump Operating Characteristics
Fig. 67 Concluded

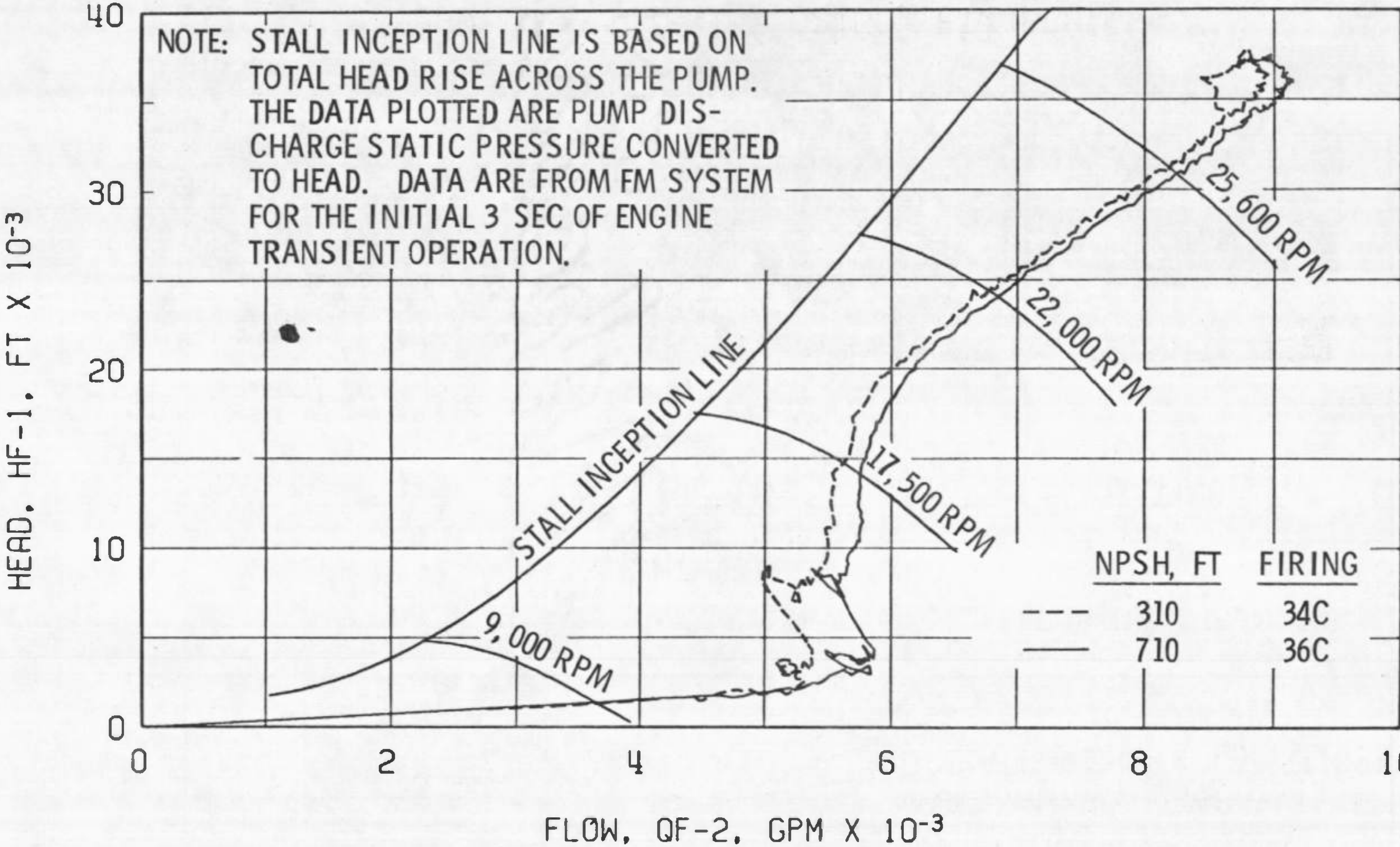


Fig. 68 Fuel Pump Start Transient Performance Comparison, Firings 34C and 36C

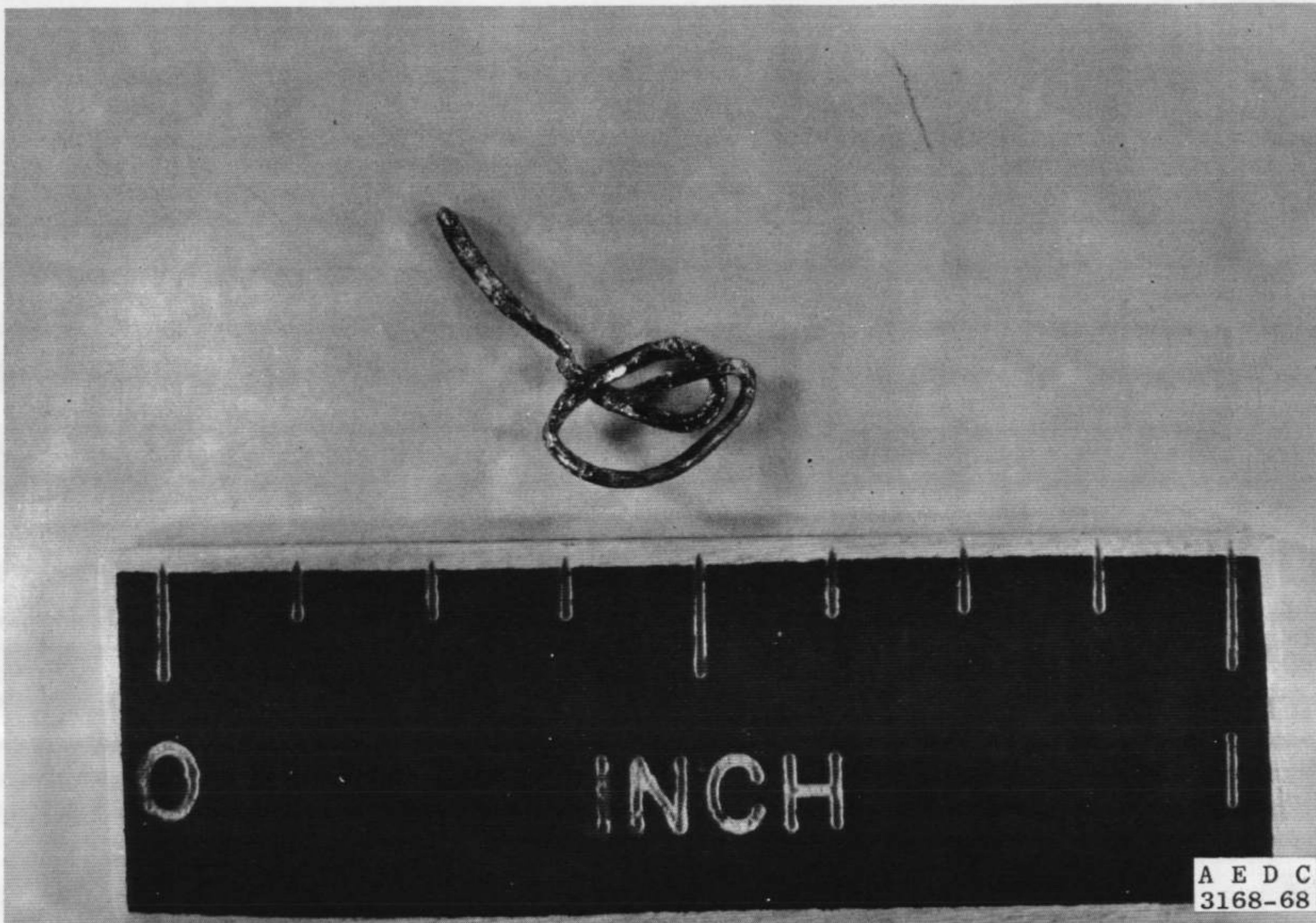


Fig. 69 Particle Removed from Main Injector Fuel Annulus, Test 35 Post Test

TABLE I
MAJOR ENGINE COMPONENTS

Part Name	P/N	S/N
Thrust Chamber Body	206600-31	4072755
Thrust Chamber Injector Assembly	208021-11	4071421
Fuel Turbopump Assembly	460160-31	4072328
Oxidizer Turbopump Assembly	458175-81	6645876
Start Tank	303439	0038
Augmented Spark Igniter	206280-81	4078806
Gas Generator Fuel Injector and Combustor	308360-11	4088543
Gas Generator Oxidizer Injector and Poppet Assembly	303323	4091740
Helium Regulator Assembly		
Tests 34 and 35	556948	4072709
Test 36	4072892	558130-111
Electrical Control Package	502670-51	4087776
Primary Flight Instrumentation Package	703685	4077391
Auxiliary Flight Instrumentation Package	703680	4077313
Main Fuel Valve		
Test 34	409120	4051082
Tests 35 and 36	409120	4062181
Main Oxidizer Valve	411031	4089563
Gas Generator Control Valve	309040-31	4062168
Start Tank Discharge Valve	304386	40865957
Oxidizer Turbine Bypass Valve	409940	4062266
Propellant Utilization Valve	251351-11	4068732

TABLE I (Concluded)

Part Name	P/N	S/N
Main-Stage Control Valve (Four-Way)		
Tests 34 and 35	555767	8284307
Test 36	558065	8275908
Ignition Phase Control Valve (Four-Way)		
Tests 34 and 35	555767	8284305
Test 36	558065	8313742
Helium Control Valve (Three-Way)		
Tests 34 and 35	NA5-27273	340919
Test 36	NA5-27273	340910
Start Tank Vent and Relief Valve		
Tests 34 and 35	557848	4092989
Test 36	558325	8358552
Helium Tank Vent Valve		
Tests 34 and 35	NA5-27273	340918
Test 36	NA5-27273	328191
Fuel Bleed Valve	309034	4077233
Oxidizer Bleed Valve	309029	4076750
Augmented Spark Igniter Oxidizer Valve	308880	4089946
Pressure-Actuated Shutdown Valve Assembly	558127-11	4087861
Pressure-Actuated Purge Control Valve	558126	4089662
Start Tank Fill/Refill Valve	558000	4072899
Fuel Flowmeter	251225	4076564
Oxidizer Flowmeter	251216	4077137
Fuel Injector Temperature Transducer	NA5-27441	12350
Restartable Ignition Detect Probe	NA5-27298T2	102

TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part Number	Diameter (Inches Unless Otherwise Noted)	Date Effective	Comments
Gas Generator Fuel Supply Line	RD251-4107-0508	0.508 in.	March 25, 1968	
Gas Generator Oxidizer Supply Line	RD251-4106-0288	0.288 in.	March 25, 1968	
Oxidizer Turbine Bypass Valve Nozzle	RD273-8002-1541	1.541 in.	March 25, 1968	
Main Oxidizer Valve Closing Control	410437-075 410437-084	8.40 scfm 8.45 scfm	March 21, 1968 (34 Pre-Test) April 8, 1968 (36 Pre-Test)	Thermostatic Orifice
Oxidizer Turbine Exhaust Manifold	RD251-9004	10.0 in.	January 18, 1966	Installed on Engine before Shipment to AEDC
Augmented Spark Igniter Oxidizer Supply Line	406361-3	0.125 in. 0.137 in.	March 21, 1968	Gives an Effective Diameter of 0.110 in.
Start Tank Discharge Valve Restrictor Check Valve Poppet	556443	0.056 in.	March 21, 1968	
Start Tank Discharge Valve C/V Orifice Plug	556433	0.063 in.	March 21, 1968	

TABLE III
ENGINE MODIFICATIONS
(BETWEEN TESTS J4-1801-34 AND J4-1801-36)

Modification Number	Completion Date	Description of Modification
RFD[1] 15-68	March 25, 1968	Replacement of Start Tank Discharge Valve
RFD 16-68	March 25, 1968	Rotation of Propellant Utilization Valve Deflector
RFD 12-68	March 25, 1968	Retimed Main Oxidizer Valve to 1750 $^{+20}_{-10}$ msec
RFD 3-68	March 25, 1968	Addition of Augmented Spark Igniter Oxidizer Orifice
RFD 69-67	March 25, 1968	Deletion of Antiflood Valve
Test J4-1801-34, March 27, 1968		
None		
Test J4-1801-35, April 2, 1968		
RFD 35-3-67	April 8, 1968	Decreased Augmented Spark Igniter Probe Immersion Depth by 0.020 in.
	April 8, 1968	Retimed Main Oxidizer Valve
Test J4-1801-36, April 10, 1968		

[1]RFD - Rocketdyne Field Directive

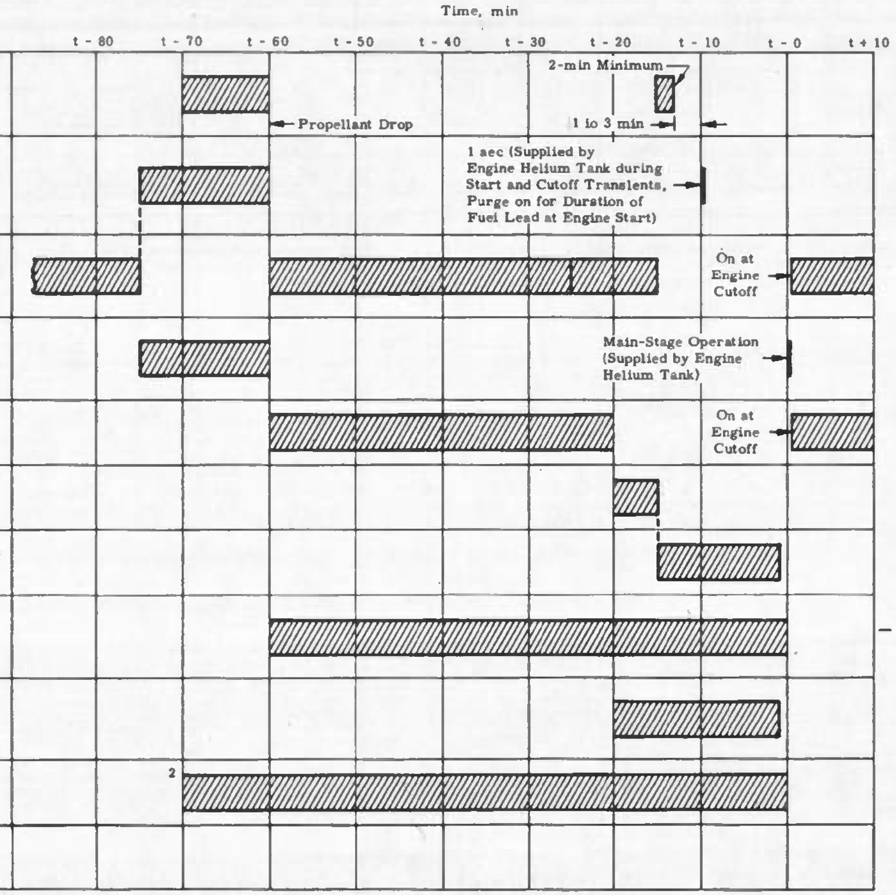
TABLE IV
ENGINE COMPONENT REPLACEMENTS
(BETWEEN TESTS J4-1801-34 AND J4-1801-36)

Replacement	Completion Date	Component Replaced
Test J4-1801-36		
UCR[1] 007387	April 8, 1968	Main Fuel Valve
UCR 007390	April 8, 1968	Pneumatic Regulator

[1]UCR - Unsatisfactory Condition Report

TABLE V
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

Turbopump and Gas Generator Purge (Purge Manifold System)	Helium; 82 - 130 psia 50 - 200°F (Nominal 6 scfm at Customer Connect
Oxidizer Dome and Gas Generator Liquid Oxygen Injector (Engine Pneumatic System)	Helium; 1400 psig 50 - 100°F (Nominal 230 scfm at Customer Connect)
Oxidizer Dome (Facility Line to Port CO3A)	Nitrogen; 415 - 875 psia 100 - 200°F 175 - 230 scfm
Oxidizer Turbopump Intermediate Seal Cavity (Engine Pneumatic System)	Helium; 1400 psig 50 - 200°F 2600 - 7000 scfm
Thrust Chamber Jacket (Customer Connect Panel)	Nitrogen; 165 - 215 psia 100 - 200°F Nominal 100 scfm
	Helium; 55 - 200 psia Ambient Temperature
Thrust Chamber Temperature Conditioning	Helium; 1000-psia Maximum Temperature as Required
Pump Inlet Pressure and Temperature Conditioning	Oxidizer; 35 to 48 psia -298 to 280°F Fuel; 28 to 48 psia -424 to 416°F
Hydrogen Start Tank and Helium Tank Pressure and Temperature Conditioning	Hydrogen; 1200 - 1400 psia -140 to -300°F Helium; 1700 - 3250 psia -140 to 300°F
Crossover Duct Temperature	Helium; -300°F to Ambient
Main Oxidizer[1] Valve Temperature	Oxidizer; -298 to -280°F



[1]Ambient Helium to be Used if Necessary to Achieve Required Target

[2]Conditioning Temperature to be Maintained for the Last 15 min before Firing except for One-Orbit Restarts

TABLE VI
SUMMARY OF TEST REQUIREMENTS AND RESULTS

Firing Number, J4-1801-34		34A Target	34A Actual	34B Target	34B Actual	34C Target	34C Actual	34D Target	34D Actual	34E Target	34E Actual
Time of Day, hr/Firing Date		1311	3-27-68	1341	3-27-68	1442	3-27-68	1726	3-27-68	1758	3-27-68
Pressure Altitude at Engine Start, ft (Ref. 1)		100,000	100,000	100,000	110,000	100,000	106,000	100,000	102,000	100,000	114,000
Firing Duration, sec ①		32.5	32.575	7.5	7.588	32.5	2.713	32.5	32.576	7.5	7.588
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	26.5^{+1}_{-0}	27.7	26.5^{+1}_{-0}	27.6	26.5^{+1}_{-0}	28.1	26.5^{+1}_{-0}	28.1	26.5^{+1}_{-0}	26.8
	Temperature, °F	-421.4 ± 0.4	-421.5	-421.4 ± 0.4	-420.8	-421.4 ± 0.4	-421.5	-421.4 ± 0.4	-421.0	-421.4 ± 0.4	-421.2
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	45.0 ± 1.0	45.7	45.0 ± 1.0	45.0	45.0 ± 1.0	46.2	45.0 ± 1.0	46.0	45.0 ± 1.0	45.1
	Temperature, °F	-295.0 ± 0.4	-295.1	-295.0 ± 0.4	-295.1	-295.0 ± 0.4	-294.6	-295.0 ± 0.4	-294.6	-295.0 ± 0.4	-293.3
Start Tank Conditions at Engine Start	Pressure, psia	1400 ± 10	1398	1300 ± 10	1254	1400 ± 10	1387	1250 ± 10	1247	1300 ± 10	1301
	Temperature, °F	-200 ± 10	-201	-215 ± 10	-216	-200 ± 10	-201	-140 ± 10	-140	-265 ± 10	-268
Helium Tank Conditions at Engine Start	Pressure, psia	-	2146	-	2186	-	2263	-	2202	-	2084
	Temperature, °F	-	-196	-	-217	-	-194	-	-139	-	-262
Thrust Chamber Temperature Conditions at Engine Start/t_0, °F	Throat (TTC-1P/TTC-2)	-80^{+20}_{-10}	-85 / -89	50 ± 50	82 / 69	-250 ± 25	-239 / -254	-80^{+20}_{-10}	-92 / -98	50 ± 50	81 / 66
	Average Engine Start/t_0	-	-111 / -184	-	+64 / -211	-	-289 / -358	-	-103 / -181	-	56 / -200
Crossover Duct Temperature at Engine Start, °F ②	TFTO-2	50^{+0}_{-50}	59	-	423	50^{+0}_{-50}	77	50^{+0}_{-50}	33	-	413
	TFTO-3	50^{+0}_{-50}	69	170^{+15}_{-0}	179	50^{+0}_{-50}	71	50^{+0}_{-50}	58	170^{+15}_{-0}	174
	TFTO-8	50^{+0}_{-50}	54	-	390	50^{+0}_{-50}	65	50^{+0}_{-50}	36	-	380
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F ③		-150 ± 50	-111	-150 ± 50	-143	-150 ± 50	-100	-150 ± 50	-132	-150 ± 50	-151
Fuel Lead Time, sec ①		3.0	3.000	8.0	7.919	3.0	3.001	3.0	3.001	8.0	7.917
Propellant in Engine Time, min		30 (Minimum)	116	-	30	30 (Minimum)	61	30 (Minimum)	165	-	32
Propellant Recirculation Time, min		10	10	10	13	10	10	10	11	10	15.5
Start Sequence Logic		Auxiliary	Auxiliary	Normal	Normal	Auxiliary	Auxiliary	Auxiliary	Auxiliary	Normal	Normal
Gas Generator Oxidizer Supply Line Temperature, °F	TOBS-2A at t_0 - 530 sec	-100 or Warmer	24	-100 or Warmer	-14	-100 or Warmer	25	-100 or Warmer	19	-100 or Warmer	-130
	TOBS-3 at Engine Start	-	Void	-	Void	-	Void	-	Void	-	Void
	TOBS-4 at Engine Start	-	-14	-	-40	-	-16	-	-20	-	-43
Start Tank Discharge Valve Body Temperature at Engine Start, °F		-	+60	-	+15	-	+37	-	-29	-	-36
Vibration Safety Counts Duration, msec and Occurrence Time, sec from t_0		- / -	17 / 0.960	- / -	7 / 0.981	- / -	47 / 0.985	- / -	17 / 0.961	- / -	5 / 0.961
Gas Generator Outlet Temperature, °F	Initial Peak	-	1645	-	1680	-	2015	-	1560	-	1905
	Second Peak	-	1700	-	1920	-	1595	-	1490	-	1880
Thrust Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0) ①		-	0.957	-	0.974	-	0.982	-	1.008	-	0.953
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0) ①		-	1.140	-	1.233	-	1.005	-	1.148	-	1.129
Main-Stage Pressure No. 2, sec (Ref. t_0) ①		-	1.600	-	1.672	-	1.630	-	1.645	-	1.645
Time Chamber Pressure Attains 550 psia, sec (Ref. t_0) ①		-	1.804	-	2.032	-	1.916	-	1.910	-	1.976
Propellant Utilization Valve Position, Engine Start/t_0 + 10 sec		Null / Closed	Null / Closed	Open / -	Open / -	Null / Closed	Null / Closed	Null / Closed	Null / Closed	Open / -	Open / -

Notes: ① Data reduced from oscillogram.
② Component conditioning to be maintained within limits for last 15 min before engine start.
③ Component conditioning to be maintained within limits for last 30 min before engine start or coast duration, whichever is longer.

TABLE VI (Continued)

Firing Number, J4-1801-35		35A Target	35A Actual	35B Target	35B Actual	35C ④ Target	35C ④ Actual
Time of day, hr/Firing Date		1239	4-2-68	1310	4-2-68		4-4-68
Pressure Altitude at Engine Start, ft (Ref. 1)		100,000	95,000	100,000	106,000	100,000	
Firing Ouration, sec ①		32.5	32.578	7.5	7.589	32.5	
Fuel Pump Inlat Conditions at Engine Start	Pressure, psia	$26.5\ ^{+1}_{-0}$	28.6	$26.5\ ^{+1}_{-0}$	27.4	41.0 ± 1.0	
	Temperature, °F	-421.4 ± 0.4	-421.2	-421.4 ± 0.4	-421.1	-421.4 ± 0.4	
Oxldizar Pump Inlet Conditions at Engine Start	Pressure, psia	45.0 ± 1.0	45.4	45.0 ± 1.0	45.6	45.0 ± 1.0	
	Temperature, °F	-295.0 ± 0.4	-295.4	-295.0 ± 0.4	-295.4	-295.0 ± 0.4	
Start Tank Conditions at Engine Start	Pressure, psia	1400 ± 10	1381	1180 ± 10	1174	1400 ± 10	
	Temperature, °F	-140 ± 10	-136	-210 ± 10	-209	-200 ± 10	
Helium Tank Conditions at Engine Start	Pressure, psia	-	2053	-	2161	-	
	Temperature, °F	-	-136	-	-206	-	
Thrust Chamber Temperature Conditions at Engine Start/t_0, °F	Throat (TTC-1P/TTC-2,	-250 ± 25	-260 / -264	50 ± 50	56 / 44	-250 ± 25	
	Average Engine Start/t_0	-	-256 / -340	-	+42 / -221	-	
Crossover Ouct Temperature at Engine Start, °F ②	TFTO-2	$50\ ^{+0}_{-50}$	16	-	411	$50\ ^{+0}_{-50}$	
	TFTO-3	$50\ ^{+0}_{-50}$	31	$170\ ^{+15}_{-0}$	183	$50\ ^{+0}_{-50}$	
	TFTO-8	$50\ ^{+0}_{-50}$	6	-	386	$50\ ^{+0}_{-50}$	
Main Oxidizer Valve Second-Stage Actuator Temperatura at Engine Start, °F ③		-150 ± 50	-115	-150 ± 50	-145	-150 ± 50	
Fuel Lead Time, sec ①		3.0	3.012	8.0	7.920	3.0	
Propellant In Engine Tima, min		30 (Minimum)	74	-	30	30 (Minimum)	
Propellant Recirculation Time, min		10	10	10	15	10	
Start Saquance Logic		Auxiliary	Auxiliary	Normal	Normal	Auxiliary	
Gas Generator Oxidizer Supply Line Temparature, °F	TOBS-2A at t_0 - 530 sec	-100 or Warmer	26	-100 or Warmer	-16	-100 or Warmer	
	TOBS-3 at Engine Start	-	Void	-	Void	-	
	TOBS-4 at Engine Start	-	-25	-	-49	-	
Start Tank Oischarge Valve Body Temperature at Engina Start, °F		-	+45	-	+9	-	
Vibration Safety Counts Duration, msec and Occurrence Time, sec from t_0		- / -	24 / 1.004	- / -	5 / 1.004	- / -	
Gas Generator Outlet Temperature, °F	Initial Peak	-	1914	-	1621	-	
	Second Peak	-	1436	-	1639	-	
Thrust Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0) ①		-	1.004	-	0.998	-	
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0) ①		-	1.008	-	1.134	-	
Main-Stage Pressure No. 2, sec (Ref. t_0) ①		-	1.689	-	1.715	-	
Time Chamber Pressure Attains 550 psia, sec (Ref. t_0) ①		-	1.957	-	2.028	-	
Propellant Utilization Valve Position, Engine Start/t_0 + 10 sec		Null / Closed	Null / Closed	Open / -	Open / -	Null / Closed	- / -

Notes: ① Data reduced from oscillogram.
② Component conditioning to be maintained within limits for last 15 min before engine start.
③ Component conditioning to be maintained within limits for last 30 min before engine start or coast duration, whichever is longer.
④ Aborted because of engine helium regulator failure.

TABLE VI (Concluded)

Firing Number, J4-1801-36		36A		36B		36C		36D		36E	
		Target	Actual	Target	Actual	Target	Actual	Target	Actual	Target	Actual
Time of day, hr/Firing Date		1539 / 4-10-68		1600 / 4-10-68		1700 / 4-10-68		1725 / 4-10-68		1834 / 4-10-68	
Pressure Altitude at Engine Start, ft (Ref. 1)		100,000	83,000	100,000	112,000	100,000	107,000	100,000	113,000	100,000	113,000
Firing Duration, sec ①		32.5	32.575	7.5	7.586	32.5	32.572	7.5	7.589	1.1	1.141
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	26.5^{+1}_{-0}	26.8	26.5^{+1}_{-0}	26.9	41.0 ± 1.0	41.4	26.5^{+1}_{-0}	26.6	26.5^{+1}_{-0}	27.9
	Temperature, °F	-421.4 ± 0.4	-421.4	-421.4 ± 0.4	-420.4	-421.4 ± 0.4	-421.4	-421.4 ± 0.4	-420.6	-421.4 ± 0.4	-420.9
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	33.0^{+1}_{-0}	33.6	45.0 ± 1.0	45.9	45.0 ± 1.0	45.2	45.0 ± 1.0	45.0	45.0 ± 1.0	44.4
	Temperature, °F	-295.0 ± 0.4	-294.6	-295.0 ± 0.4	-294.4	-295.0 ± 0.4	-294.8	-295.0 ± 0.4	-294.8	-295.0 ± 0.4	-294.3
Start Tank Conditions at Engine Start	Pressure, psia	1250 ± 10	1250	1200 ± 10	1205	1400 ± 10	1388	1300 ± 10	1298	1400 ± 10	1388
	Temperature, °F	-140 ± 10	-139	-260 ± 10	-260	-200 ± 10	-202	-265 ± 10	-266	-200 ± 10	-199
Helium Tank Conditions at Engine Start	Pressure, psia	-	2270	-	1949	-	2299	-	2024	-	2532
	Temperature, °F	-	-135	-	-244	-	-199	-	-257	-	-198
Thrust Chamber Temperature Conditions at Engine Start/t_0, °F	Throat (TTC-1P/TTC-2)	-200 ± 25	-192 / -201	+50 ± 50	44 / 30	-250 ± 25	-236 / -244	-200 ± 25	-198 / -208	0 ± 15	-8 / -13
	Average Engine Start/t_0	-	-182 / -356	-	+36 / -215	-	-278 / -355	-	-210 / -362	-	-14 / -91
Crossover Duct Temperature at Engine Start, °F ②	TFTD-2	-100 ± 20	-97	-	388	$+50^{+0}_{-50}$	76	-	450	$+50^{+0}_{-50}$	23
	TFTD-3	-100 ± 20	-92	$+170^{+15}_{-0}$	168	$+50^{+0}_{-50}$	73	$+170^{+15}_{-0}$	174	$+50^{+0}_{-50}$	24
	TFTD-8	-100 ± 20	-91	-	384	$+50^{+0}_{-50}$	65	-	408	$+50^{+0}_{-50}$	20
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F ③		-150 ± 50	-119	-150 ± 50	-135	-150 ± 50	-160	-150 ± 50	-157	-	-
Fuel Lead Time, sec ①		8.0	7.918	8.0	7.917	3.0	3.009	8.0	7.920	3.0	3.001
Propellant in Engine Time, min		30 (Minimum)	84	-	22	30 (Minimum)	61	-	27	30 (Minimum)	69
Propellant Recirculation Time, min		10	13	10	4.5	10	10	10	10.5	10	10
Start Sequence Logic		Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Auxiliary	Auxiliary
Gas Generator Oxidizer Supply Line Temperature, °F	TOBS-2A at t_0 - 530 sec	-100 or Warmer	+17	-100 or Warmer	-37	-100 or Warmer	+16	-100 or Warmer	-20	-100 or Warmer	+12
	TOBS-3 at Engine Start	-	Void	-	Void	-	Void	-	Void	-	Void
	TOBS-4 at Engine Start	-	-20	-	-47	-	-26	-	-44	-	-31
Start Tank Discharge Valve Body Temperature at Engine Start, °F		-	+40	-	+16	-	-44	-	-42	-	-78
Vibration Safety Counts Duration, msec and Occurrence Time, sec from t_0		- / -	42 / 1.066	- / -	5 / 0.982	- / -	36 / 0.980	- / -	109/121 / 0.957	- / -	- / -
Gas Generator Outlet Temperature, °F	Initial Peak	-	880	-	1971	-	2142	-	2160	-	1585
	Second Peak	-	-	-	1836	-	1528	-	-	-	-
Thrust Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0) ①		-	1.079	-	0.973	-	0.980	-	0.957	-	0.975
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0) ①		-	0.987	-	1.112	-	0.985	-	0.979	-	1.094
Main-Stage Pressure No. 2, sec (Ref. t_0) ①		-	2.121	-	1.693	-	1.585	-	1.665	-	-
Time Chamber Pressure Attains 550 psia, sec (Ref. t_0) ①		-	2.800	-	2.052	-	1.879	-	2.023	-	-
Propellant Utilization Valve Position, Engine Start/t_0 + 10 sec		Open / Close	Open / Close	Open / -	Open / -	Null / Close	Null / Close	Open / -	Open / -	Null / -	Null / -

Notes: ① Data reduced from oscillogram.
② Component conditioning to be maintained within limits for last 15 min before engine start.
③ Component conditioning to be maintained within limits for last 30 min before engine start or coast duration, whichever is longer.

TABLE VII
ENGINE VALVE TIMINGS

Firing Number J4-1801-	Start											
	Start Tank Discharge Valve			Main Fuel Valve			Main Oxidizer Valve First Stage			Main Oxidizer Valve Second Stage		
	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
34A	0	0.129	0.109	-3.000	0.057	0.068	0.449	0.057	0.053	0.449	0.591	2.042
34B	0	0.128	0.115	-7.918	0.056	0.084	0.448	0.059	0.060	0.448	0.785	1.828
34C	0	0.130	0.109	-3.001	0.057	0.085	0.449	0.058	0.055	0.449	0.556	N/A
34D	0	0.133	0.117	-3.000	0.055	0.074	0.449	0.059	0.058	0.449	0.699	1.995
34E	0	0.136	0.110	-7.917	0.068	0.075	0.448	0.058	0.058	0.448	0.681	1.895
34 Final Sequence	0	0.090	0.097	-0.999	0.047	0.085	0.450	0.053	0.045	0.450	0.573	1.742

Firing Number J4-1801-	Start											
	Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve			Start Tank Discharge Valve		
	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
34A	0.449	0.113	0.025	0.449	0.179	0.081	0.449	0.211	0.305	0.449	0.122	0.238
34B	0.448	0.123	0.025	0.448	0.192	0.088	0.448	0.206	0.298	0.448	0.128	0.246
34C	0.449	0.118	0.021	0.449	0.178	0.078	0.449	0.214	0.294	0.449	0.125	0.242
34D	0.449	0.118	0.022	0.449	0.179	0.071	0.449	0.224	0.304	0.449	0.132	0.258
34E	0.448	0.123	0.025	0.448	0.194	0.090	0.448	0.210	0.297	0.448	0.132	0.255
34 Final Sequence	0.450	0.094	0.026	0.450	0.145	0.070	0.450	0.201	0.299	0.450	0.129	0.241

Firing Number J4-1801-	Shutdown														
	Main Fuel Valve			Main Oxidizer Valve			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
34A	32.575	0.114	0.327	32.575	0.081	0.187	32.575	0.075	0.021	32.575	0.034	0.014	32.575	0.229	0.462
34B	7.590	0.112	0.323	7.590	0.081	0.184	7.590	0.080	0.022	7.590	0.039	0.017	7.590	0.209	0.426
34C	2.713	0.117	0.335	2.713	N/A	N/A	2.713	0.079	0.018	2.713	0.037	0.016	2.713	0.198	0.476
34D	32.576	0.126	0.377	32.576	0.082	0.191	32.576	0.086	0.025	32.576	0.041	0.018	32.576	0.233	0.475
34E	7.588	0.116	0.342	7.588	0.079	0.191	7.588	0.082	0.022	7.588	0.038	0.021	7.588	0.210	0.433
34 Final Sequence	---	0.083	0.236	---	0.066	0.128	---	0.100	0.037	---	0.063	0.029	---	0.214	0.541

Notes: 1. All valve signal times are referenced to t_0.
2. Valve delay time is the time required for initial valve movement after the valve "open" or valve "closed" solenoid has been energized.
3. Final sequence check is conducted without propellants and within 12 hr before testing.
4. Data are reduced from oscillogram.

TABLE VII (Continued)

Firing Number J4-1801-	Start: Start Tank Discharge Valve, Time of Opening Signal	Start: Start Tank Discharge Valve, Valve Delay Time, sec	Start: Start Tank Discharge Valve, Valve Opening Time, sec	Start: Main Fuel Valve, Time of Opening Signal	Start: Main Fuel Valve, Valve Delay Time, sec	Start: Main Fuel Valve, Valve Opening Time, sec	Start: Main Oxidizer Valve First Stage, Time of Opening Signal	Start: Main Oxidizer Valve First Stage, Valve Delay Time, sec	Start: Main Oxidizer Valve First Stage, Valve Opening Time, sec	Start: Main Oxidizer Valve Second Stage, Time of Opening Signal	Start: Main Oxidizer Valve Second Stage, Valve Delay Time, sec	Start: Main Oxidizer Valve Second Stage, Valve Opening Time, sec
35A	0	0.128	0.112	-3.012	0.063	0.058	0.448	0.059	0.052	0.448	0.560	2.070
35B	0	0.126	0.111	-7.920	0.056	0.085	0.448	0.061	0.058	0.448	0.686	1.876
35 Final Sequence	-	0.091	0.095	-7.936	0.048	0.076	0.450	0.054	0.044	0.450	0.571	1.735

Firing Number J4-1801-	Start: Gas Generator Fuel Poppet, Time of Opening Signal	Start: Gas Generator Fuel Poppet, Valve Delay Time, sec	Start: Gas Generator Fuel Poppet, Valve Opening Time, sec	Start: Gas Generator Oxidizer Poppet, Time of Opening Signal	Start: Gas Generator Oxidizer Poppet, Valve Delay Time, sec	Start: Gas Generator Oxidizer Poppet, Valve Opening Time, sec	Start: Oxidizer Turbine Bypass Valve, Time of Closing Signal	Start: Oxidizer Turbine Bypass Valve, Valve Delay Time, sec	Start: Oxidizer Turbine Bypass Valve, Valve Closing Time, sec	Start: Start Tank Discharge Valve, Time of Closing Signal	Start: Start Tank Discharge Valve, Valve Delay Time, sec	Start: Start Tank Discharge Valve, Valve Closing Time, sec
35A	0.448	0.118	0.024	0.448	0.179	0.084	0.448	0.223	0.294	0.448	0.126	0.240
35B	0.448	0.124	0.023	0.448	0.190	0.088	0.448	0.205	0.307	0.448	0.130	0.246
35 Final Sequence	0.450	0.093	0.031	0.450	0.145	0.075	0.450	0.206	0.301	0.450	0.137	0.245

Firing Number J4-1801-	Shutdown: Main Fuel Valve, Time of Closing Signal	Shutdown: Main Fuel Valve, Valve Delay Time, sec	Shutdown: Main Fuel Valve, Valve Closing Time, sec	Shutdown: Main Oxidizer Valve, Time of Closing Signal	Shutdown: Main Oxidizer Valve, Valve Delay Time, sec	Shutdown: Main Oxidizer Valve, Valve Closing Time, sec	Shutdown: Gas Generator Fuel Poppet, Time of Closing Signal	Shutdown: Gas Generator Fuel Poppet, Valve Delay Time, sec	Shutdown: Gas Generator Fuel Poppet, Valve Closing Time, sec	Shutdown: Gas Generator Oxidizer Poppet, Time of Closing Signal	Shutdown: Gas Generator Oxidizer Poppet, Valve Delay Time, sec	Shutdown: Gas Generator Oxidizer Poppet, Valve Closing Time, sec	Shutdown: Oxidizer Turbine Bypass Valve, Time of Opening Signal	Shutdown: Oxidizer Turbine Bypass Valve, Valve Delay Time, sec	Shutdown: Oxidizer Turbine Bypass Valve, Valve Opening Time, sec
35A	32.578	0.118	0.332	32.578	0.082	0.189	32.578	0.073	0.021	32.578	0.031	0.016	32.578	0.235	0.481
35B	7.589	0.110	0.319	7.589	0.073	0.194	7.589	0.080	0.020	7.589	0.036	0.017	7.589	0.212	0.439
35 Final Sequence	-	0.082	0.241	-	0.059	0.131	-	0.103	0.030	-	0.064	0.031	-	0.213	0.549

Notes:
1. All valve signal times are referenced to t_0.
2. Valve delay time is the time required for initial valve movement after the valve "open" or valve "closed" solenoid has been energized.
3. Final sequence check is conducted without propellants and within 12 hr before testing.
4. Data are reduced from oscillograms.

TABLE VII (Concluded)

Firing Number J4-1801-	Start: Start Tank Discharge Valve			Main Fuel Valve			Main Oxidizer Valve First Stage			Main Oxidizer Valve Second Stage		
	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
36A	0	0.126	0.109	-7.918	0.057	0.065	0.449	0.059	0.049	0.449	0.538	1.835
36B	0	0.127	0.111	-7.917	0.054	0.088	0.450	0.058	0.054	0.450	0.662	1.974
36C	0	0.140	0.128	-3.006	0.056	0.086	0.450	0.058	0.054	0.450	0.535	2.188
36D	0	0.139	0.123	-7.920	0.059	0.087	0.449	0.059	0.055	0.449	0.530	2.065
36E	0	0.146	0.132	-3.001	0.054	0.081	0.450	0.057	0.057	0.450	0.644	-
Final Sequence	0	0.090	0.092	-1.000	0.046	0.079	0.451	0.049	0.044	0.451	0.567	1.727

Firing Number J4-1801-	Start: Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve			Start Tank Discharge Valve		
	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
36A	0.449	0.121	0.021	0.449	0.179	0.080	0.449	0.225	0.304	0.449	0.124	0.241
36B	0.450	0.125	0.023	0.450	0.197	0.095	0.450	0.225	0.311	0.450	0.129	0.243
36C	0.450	0.124	0.024	0.450	0.197	0.093	0.450	0.220	0.283	0.450	0.130	0.250
36D	0.449	0.124	0.030	0.449	0.200	0.092	0.449	0.216	0.324	0.449	0.132	0.245
36E	0.450	0.126	0.027	0.450	0.204	0.102	0.450	0.214	0.308	0.450	0.134	0.262
Final Sequence	0.451	0.093	0.024	0.451	0.142	0.075	0.451	0.211	0.300	0.451	0.123	0.243

Firing Number J4-1801-	Shutdown: Main Fuel Valve			Main Oxidizer Valve			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
36A	32.575	0.113	0.328	32.575	0.080	0.191	32.575	0.074	0.017	32.575	0.033	0.016	32.575	0.267	0.469
36B	7.586	0.110	0.306	7.586	0.077	0.187	7.586	0.082	0.024	7.586	0.038	0.023	7.586	0.230	0.464
36C	32.572	0.115	0.341	32.572	0.086	0.201	32.572	0.078	0.023	32.572	0.033	0.015	32.572	0.226	0.422
36D	7.589	0.109	0.328	7.589	0.077	0.189	7.589	0.083	0.020	7.589	0.038	0.018	7.589	0.208	0.391
36E	1.141	0.110	0.314	1.141	-	-	1.141	0.093	0.021	1.141	0.051	0.027	1.141	0.117	0.469
Final Sequence	-	0.082	0.237	-	0.061	0.128	-	0.099	0.030	-	0.060	0.029	-	0.206	0.523

Notes: 1. All valve signal times are referenced to t_0.
2. Valve delay time is the time required for initial valve movement after the valve "open" or valve "closed" solenoid has been energized.
3. Final sequence check is conducted without propellants and within 12 hr before testing.
4. Data are reduced from oscillogram.

TABLE VIII
ENGINE PERFORMANCE SUMMARY

Firing Number J4-1801-		34A		34D		35A		36A		36C	
		Site	Normalized	Site	Normalized	Site	Normalized	Site	Normalized	Site	Normalized
Overall Engine Performance	Thrust, lb_f	235,126	232,475	232,649	231,003	234,193	231,940	233,722	231,347	233,923	231,388
	Chamber Pressure, psia	793	781	785	776	790	779	789	777	789	777
	Mixture Ratio	5.44	5.43	5.46	5.44	5.46	5.43	5.44	5.43	5.39	5.42
	Fuel Weight Flow, lb_m/sec	86.7	85.5	85.7	84.9	86.5	85.6	86.3	85.1	87.0	85.4
	Oxidizer Weight Flow, lb_m/sec	471.8	464.1	467.7	462.0	472.6	465.3	469.4	462.5	469.1	462.8
	Total Weight Flow, lb_m/sec	558.6	549.7	553.4	547.0	559.1	550.9	555.8	547.6	556.1	548.2
Thrust Chamber Performance	Mixture Ratio	5.65	5.63	5.67	5.65	5.67	5.64	5.64	5.64	5.59	5.62
	Total Weight Flow, lb_m/sec	551.1	542.3	546.1	539.7	551.7	543.5	548.5	540.4	548.8	541.0
	Characteristic Velocity, ft/sec	7881	7883	7868	7872	7842	7848	7872	7872	7870	7860
Fuel Turbopump Performance	Pump Efficiency, percent	72.7	72.7	72.6	72.6	72.8	72.8	72.8	72.8	72.7	72.6
	Pump Speed, rpm	27,897	27,688	27,787	27,544	27,844	27,591	27,765	27,592	27,859	27,607
	Turbine Efficiency, percent	62.7	62.6	62.4	62.3	62.4	62.3	62.9	62.8	63.3	63.1
	Turbine Pressure Ratio	7.34	7.34	7.33	7.32	7.37	7.37	7.28	7.28	7.30	7.29
	Turbine Inlet Temperature, °F	1239	1217	1240	1215	1251	1224	1245	1226	1244	1228
	Turbine Weight Flow, lb_m/sec	7.41	7.34	7.33	7.30	7.40	7.34	7.30	7.23	7.31	7.23
Oxidizer Turbopump Performance	Pump Efficiency, percent	80.4	80.4	80.4	80.4	80.5	80.5	80.4	80.4	80.4	80.4
	Pump Speed, rpm	8782	8710	8761	8694	8755	8690	8755	8683	8751	8679
	Turbine Efficiency, percent	49.5	49.3	49.6	49.5	49.6	49.5	50.7	50.5	50.7	50.5
	Turbine Pressure Ratio	2.65	2.65	2.64	2.64	2.65	2.65	2.63	2.63	2.62	2.62
	Turbine Inlet Temperature, °F	793	777	792	774	799	780	785	772	790	780
	Turbine Weight Flow, lb_m/sec	6.44	6.38	6.37	6.34	6.44	6.39	6.33	6.27	6.34	6.28
Gas Generator Performance	Mixture Ratio	0.96	0.95	0.96	0.95	0.97	0.95	0.97	0.96	0.97	0.96
	Chamber Pressure, psia	721	712	714	708	722	713	711	702	712	703

Note: 1. Site data are calculated from test data.
2. Normalized data are corrected to standard pump inlet and engine ambient pressure conditions.
3. Input data are test data averaged from 29 to 30 sec, except as noted.
4. Site and normalized data were computed using the Rocketdyne PAST 640 modification zero computer program.

APPENDIX III
INSTRUMENTATION

The instrumentation for AEDC tests J4-1801-34 through 36 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III-1.

TABLE III-1
INSTRUMENTATION LIST (FOR TESTS J4-1801-34 THROUGH J4-1801-36)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Current		amp					
ICC	Control		0 to 30	x		x		
IIC	Ignition		0 to 30	x		x		
	Event							
EASIOV	Augmented Spark Igniter Oxidizer Valve Open		On/Off	x		x		
EECL	Engine Cutoff Lockin		On/Off	x		x		
EECO	Engine Cutoff Signal		On/Off	x	x	x		
EES	Engine Start Command		On/Off	x		x		
EFBVC	Fuel Bleed Valve Closed Limit		Open/Closed	x				
EFPVC/O	Fuel Prevalve Closed/Open Limit		Closed/Open	x				
EHCS	Helium Control Solenoid		On/Off	x		x		
EID	Ignition Detected		On/Off	x		x		
EIPCS	Ignition Phase Control Solenoid		On/Off	x		x		
EMCS	Main-Stage Control Solenoid		On/Off	x		x		
EMP-1	Main-Stage Pressure No. 1		On/Off	x		x		
EMP-2	Main-Stage Pressure No. 2		On/Off	x		x		
EOBVC	Oxidizer Bleed Valve Closed Limit		Open/Closed	x				
EOPVC	Oxidizer Prevalve Closed Limit		Closed	x		x		
EOPVO	Oxidizer Prevalve Open Limit		Open	x		x		
ESTDCS	Start Tank Discharge Control Solenoid		On/Off	x	x	x		
RASIS-1	Augmented Spark Igniter Spark No. 1		On/Off			x		
RASIS-2	Augmented Spark Igniter Spark No. 2		On/Off			x		
RGGS-1	Gas Generator Spark No. 1		On/Off			x		
RGGS-2	Gas Generator Spark No. 2		On/Off			x		
	Flows		gpm					
QF-1A	Fuel	PFF	0 to 9000	x		x		
QF-2	Fuel	PFFA	0 to 9000	x	x	x		
QF-1SAM	Fuel Flow Stall Approach Monitor		0 to 9000	x		x		
QFRP	Fuel Recirculation		0 to 160	x				
QO-1A	Oxidizer	POF	0 to 3000	x		x		
QO-2	Oxidizer	POFA	0 to 3000	x	x	x		
QORP	Oxidizer Recirculation		0 to 50	x			x	
	Position		Percent Open					
LFVT	Main Fuel Valve		0 to 100	x		x		
LGGVT	Gas Generator Valve		0 to 100	x		x		
LOTBVT	Oxidizer Turbine Bypass Valve		0 to 100	x		x		
LOVT	Main Oxidizer Valve		0 to 100	x	x	x		
LPUTOP	Propellant Utilization Valve		0 to 100	x		x	x	
LSTDVT	Start Tank Discharge Valve		0 to 100	x		x		
	Pressure		psia					
PA1	Test Cell		0 to 0.5	x		x		
PA2	Test Cell		0 to 1.0	x	x			
PA3	Test Cell		0 to 5.0	x			x	
PC-1P	Thrust Chamber	CG1	0 to 1000	x			x	
PC-3	Thrust Chamber	CG1A	0 to 1000	x	x	x		
PCBO-1	Constant Bleed Orifice		0 to 50	x				
PCGG-1P	Gas Generator Chamber Pressure		0 to 1000	x	x	x		
PCGG-2	Gas Generator Chamber	GG1A	0 to 1000	x				
PFASIJ	Augmented Spark Igniter Fuel Injection		0 to 1000	x				
PFJ-1A	Main Fuel Injection	CF2	0 to 1000	x		x		
PFJ-2	Main Fuel Injection	CF2A	0 to 1000	x	x			
PFJGG-1A	Gas Generator Fuel Injection	GF4	0 to 1000	x				
PFJGG-2	Gas Generator Fuel Injection	GF4	0 to 1000	x		x		
PFMI	Fuel Jacket Inlet Manifold	CF1	0 to 2000	x				
PFPC-1A	Fuel Pump Balance Piston Cavity	PF5	0 to 1000	x				
PFPD-1P	Fuel Pump Discharge	PF3	0 to 1500	x				x
PFPD-2	Fuel Pump Discharge	PF2	0 to 1500	x	x	x		
PFPI-1	Fuel Pump Inlet		0 to 100	x		x		x
PFPI-2	Fuel Pump Inlet		0 to 200	x		x		x
PFPI-3	Fuel Pump Inlet		0 to 200		x			
PFPPSD-1	Fuel Pump Primary Seal Drain		0 to 200	x				
PFPPSD-2	Fuel Pump Primary Seal Drain		0 to 100	x				

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Pressure		psia					
PFPS-1P	Fuel Pump Interstage	PF6	0 to 200	x				
PFRPO	Fuel Recirculation Pump Outlet		0 to 60	x				
PFRPR	Fuel Recirculation Pump Return		0 to 50	x				
PFST-1P	Fuel Start Tank	TF1	0 to 1500	x		x		
PFST-2	Fuel Start Tank	TF1	0 to 1500	x				x
PFTSP-1	Fuel Turbine Seal Purge Line		0 to 100	x				
PFUT	Fuel Tank Ullage		0 to 100	x				
PFVI	Fuel Tank Pressurization Line Nozzle Inlet		0 to 1000	x				
PFVL	Fuel Tank Pressurization Line Nozzle Throat		0 to 1000	x				
PGGOC	Gas Generator Opening Control		0 to 500	x				
PGGVB	Gas Generator Valve Body		0 to 50	x				
PHECMO	Pneumatic Control Module Outlet		0 to 750	x				
PHEOP	Oxidizer Recirculation Pump Purge		0 to 150	x				
PHES	Helium Supply		0 to 5000	x				
PHET-1P	Helium Tank	NN1	0 to 3500	x		x		
PHET-2	Helium Tank	NN1	0 to 3500	x				x
PHRO-1A	Helium Regulator Outlet	NN2	0 to 750	x	x			
POBSC	Oxidizer Bootstrap Conditioning		0 to 50	x				
POBV	Gas Generator Oxidizer Bleed Valve	GO2	0 to 2000	x				
POJ-1A	Main Oxidizer Injection	CO3	0 to 1000	x		x		
POJ-2	Main Oxidizer Injection	CO3A	0 to 1000	x		x		
POJGG-1A	Gas Generator Oxidizer Injection	GO5	0 to 1000	x		x		
POJGG-2	Gas Generator Oxidizer Injection	GO5	0 to 1000	x		x		
POPBC-1A	Oxidizer Pump Bearing Coolant	PO7	0 to 500	x				
POPD-1P	Oxidizer Pump Discharge	PO3	0 to 1500	x				
POPD-2	Oxidizer Pump Discharge	PO2	0 to 1500	x	x	x		
POPI-1	Oxidizer Pump Inlet		0 to 100	x				x
POPI-2	Oxidizer Pump Inlet		0 to 200	x				x
POPI-3	Oxidizer Pump Inlet		0 to 100			x		
POPSC-1A	Oxidizer Pump Primary Seal Cavity	PO6	0 to 50	x				
PORPO	Oxidizer Recirculation Pump Outlet		0 to 115	x				
PORPR	Oxidizer Recirculation Pump Return		0 to 100	x				
POTI-1A	Oxidizer Turbine Inlet	TG3	0 to 200	x				
POTO-1A	Oxidizer Turbine Outlet	TG4	0 to 100	x				
POUT	Oxidizer Tank Ullage		0 to 100	x				
POVCC	Main Oxidizer Valve Closing Control		0 to 500	x	x			
POVI	Oxidizer Tank Pressurization Line Nozzle Inlet		0 to 1000	x				
POVL	Oxidizer Tank Pressurization Line Nozzle Throat		0 to 1000	x				
PPUVI-1A	Propellant Utilization Valve Inlet	PO8	0 to 1000	x				
PPUVO-1A	Propellant Utilization Valve Outlet	PO9	0 to 500	x				
PTCFJP	Thrust Chamber Fuel Jacket Purge		0 to 100	x				
PTCP	Thrust Chamber Purge		0 to 15	x				
PTPP	Turbopump and Gas Generator Purge		0 to 250	x				
	Speeds		rpm					
NFP-1P	Fuel Pump	PFV	0 to 30,000	x	x	x		
NFRP	Fuel Recirculation Pump		0 to 15,000	x				
NOP-1P	Oxidizer Pump	POV	0 to 12,000	x	x	x		
NORP	Oxidizer Recirculation Pump		0 to 15,000	x				
	Temperatures		°F					
C2036	Temperature Oxidizer Bootstrap		-300 to +250	x				
C2037	Temperature Oxidizer Bootstrap		-300 to +250	x				
TA1	Test Cell (North)		-50 to +800	x				
TA2	Test Cell (East)		-50 to +800	x				
TA3	Test Cell (South)		-50 to +800	x				
TA4	Test Cell (West)		-50 to +800	x				
TAIP-1A	Auxiliary Instrument Package		-300 to +200	x				
TBPM	Bypass Manifold		-325 to +200	x				
TBSC	Oxidizer Bootstrap Conditioning		-350 to +150	x				
TECP-1P	Electrical Controls Package	NST1A	-300 to +200	x			x	
TFASIJ	Augmented Spark Igniter Fuel Injection	IFT1	-425 to +100	x		x		
TFASIL-1	Augmented Spark Igniter Line		-300 to +200	x				
TFASIL-2	Augmented Spark Igniter Line		-300 to +300	x				
TFBV-1A	Fuel Bleed Valve	GFT1	-425 to -375	x				
TFD-1	Fire Detection		0 to 1000	x			x	
TFJ-1P	Main Fuel Injection	CFT2	-425 to +250	x	x	x		

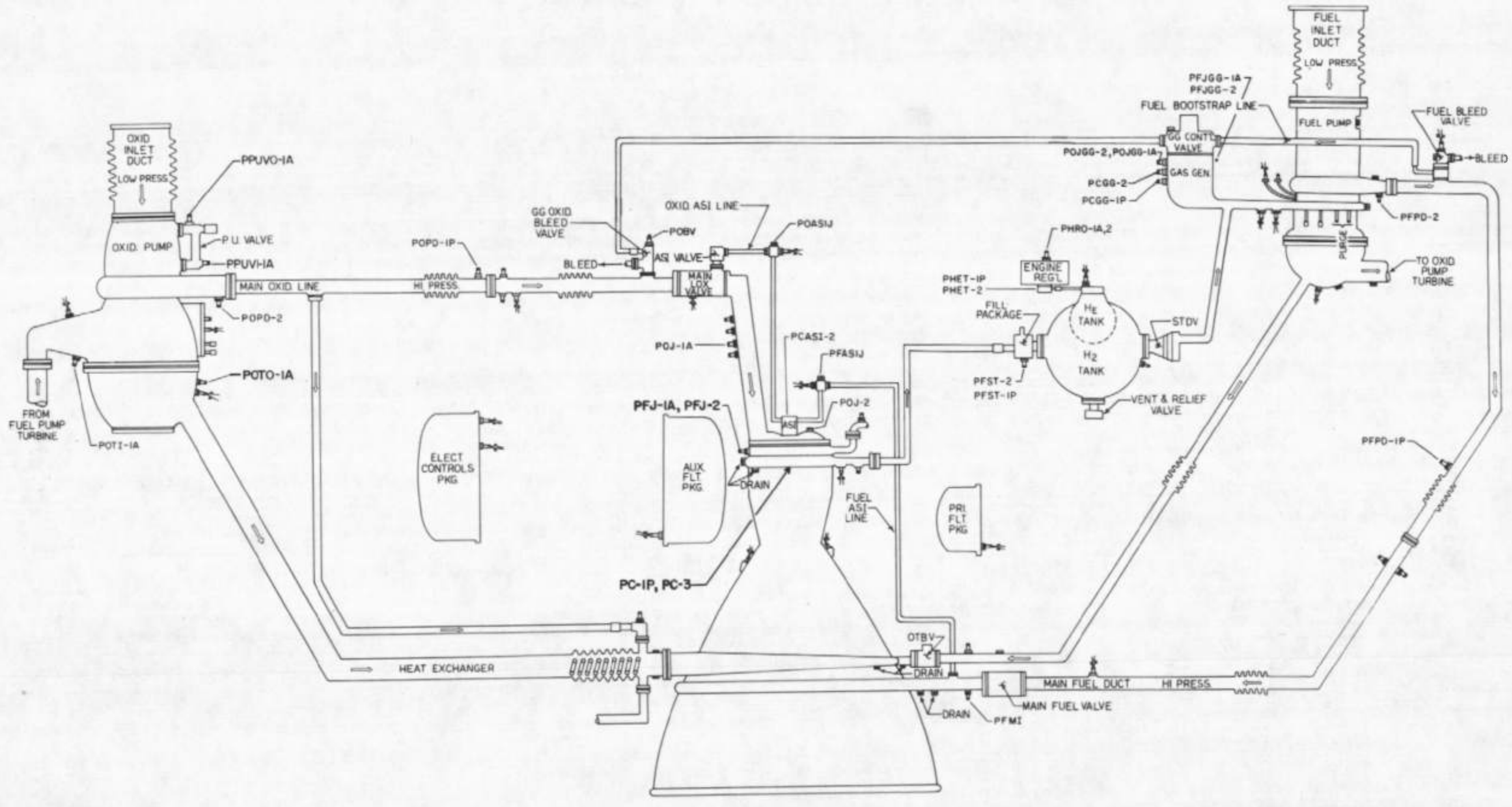
TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -400	x	x	x		
TFPD-2	Fuel Pump Discharge	PFT1	-425 to -400	x				
TFPDD	Fuel Pump Discharge Duct		-320 to +300	x				
TFPI-1	Fuel Pump Inlet		-425 to -400	x				x
TFPI-2	Fuel Pump Inlet		-425 to -400	x				x
TFPPSD-1	Fuel Pump Primary Seal Drain		-425 to +100	x				
TFPSP-1	Fuel Pump Seal Purge		-425 to +100	x				
TFRPO	Fuel Recirculation Pump Outlet		-425 to -410	x				
TFRPR	Fuel Recirculation Pump Return Line		-425 to -250	x				
TFRT-1	Fuel Tank		-425 to -410	x				
TFRT-3	Fuel Tank		-425 to -410	x				
TFST-1P	Fuel Start Tank	TFT1	-350 to +100	x				
TFST-2	Fuel Start Tank	TFT1	-350 to +100	x				x
TFTD-1	Fuel Turbine Discharge Duct		-200 to +800	x				
TFTD-2	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-4	Fuel Turbine Discharge Duct		-200 to +1000	x				
TFTD-5	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-6	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-7	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-8	Fuel Turbine Discharge Duct		-200 to +1400	x			x	
TFTO	Fuel Turbine Outlet	TFT2	0 to 1800	x				
TFTSD-1	Fuel Turbine Seal Drain Line		-300 to +100	x				
TGGO-1A	Gas Generator Outlet	GGT1	0 to 1800	x		x	x	
TGGVRS	Gas Generator Valve Retaining Screw		-100 to +100	x			x	
THET-1P	Helium Tank	NNT1	-350 to +100	x				x
TMFV-1	Main Fuel Valve		-100 to +300	x				
TMFV-2	Main Fuel Valve		-100 to +300	x				
TNODP	Liquid Oxygen Dome Purge		0 to -300	x				
TOBS-1	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2A	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2B	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-4	Oxidizer Bootstrap Line		-300 to +250	x				
TOBV-1A	Oxidizer Bleed Valve	GOT2	-300 to -250	x				
TOPB-1A	Oxidizer Pump Bearing Coolant	POT4	-300 to -250	x				
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x	x	x	x	
TOPD-2	Oxidizer Pump Discharge	POT3	-300 to -250	x				
TOPI-1	Oxidizer Pump Inlet		-310 to -270	x				x
TOPI-2	Oxidizer Pump Inlet		-310 to -270	x				x
TORPO	Oxidizer Recirculation Pump Outlet		-300 to -250	x				
TORPR	Oxidizer Recirculation Pump Return		-300 to -140	x				
TORT-1	Oxidizer Tank		-300 to -287	x				
TORT-1B	Oxidizer Tank		-300 to -287	x				
TORT-3	Oxidizer Tank		-300 to -287	x				
TOTI-1P	Oxidizer Turbine Inlet	TGT3	0 to 1200	x			x	
TOTO-1P	Oxidizer Turbine Outlet	TGT4	0 to 1000	x				
TOVL	Oxidizer Tank Pressurization Line Nozzle Throat		-300 to +100	x				
TPCC	Prechill Controller		-425 to -300	x				
TPIP-1P	Primary Instrument Package		-300 to +200	x				
TSC2-1	Thrust Chamber Skin		-300 to +500	x				
TSC2-2	Thrust Chamber Skin		-300 to +500	x				
TSC2-3	Thrust Chamber Skin		-300 to +500	x				
TSC2-4	Thrust Chamber Skin		-300 to +500	x				
TSC2-5	Thrust Chamber Skin		-300 to +500	x				
TSC2-6	Thrust Chamber Skin		-300 to +500	x				
TSC2-7	Thrust Chamber Skin		-300 to +500	x				
TSC2-8	Thrust Chamber Skin		-300 to +500	x				
TSC2-9	Thrust Chamber Skin		-300 to +500	x				
TSC2-10	Thrust Chamber Skin		-300 to +500	x				
TSC2-11	Thrust Chamber Skin		-300 to +500	x				
TSC2-12	Thrust Chamber Skin		-300 to +500	x				
TSC2-13	Thrust Chamber Skin		-300 to +500	x			x	
TSC2-14	Thrust Chamber Skin		-300 to +500	x				
TSC2-15	Thrust Chamber Skin		-300 to +500	x				
TSC2-16	Thrust Chamber Skin		-300 to +500	x				
TSC2-17	Thrust Chamber Skin		-300 to +500	x				
TSC2-18	Thrust Chamber Skin		-300 to +500	x				
TSC2-19	Thrust Chamber Skin		-300 to +500	x				
TSC2-20	Thrust Chamber Skin		-300 to +500	x				
TSC2-21	Thrust Chamber Skin		-300 to +500	x				
TSC2-22	Thrust Chamber Skin		-300 to +500	x				
TSC2-23	Thrust Chamber Skin		-300 to +500	x				
TSC2-24	Thrust Chamber Skin		-300 to +500	x				

TABLE III-1 (Concluded)

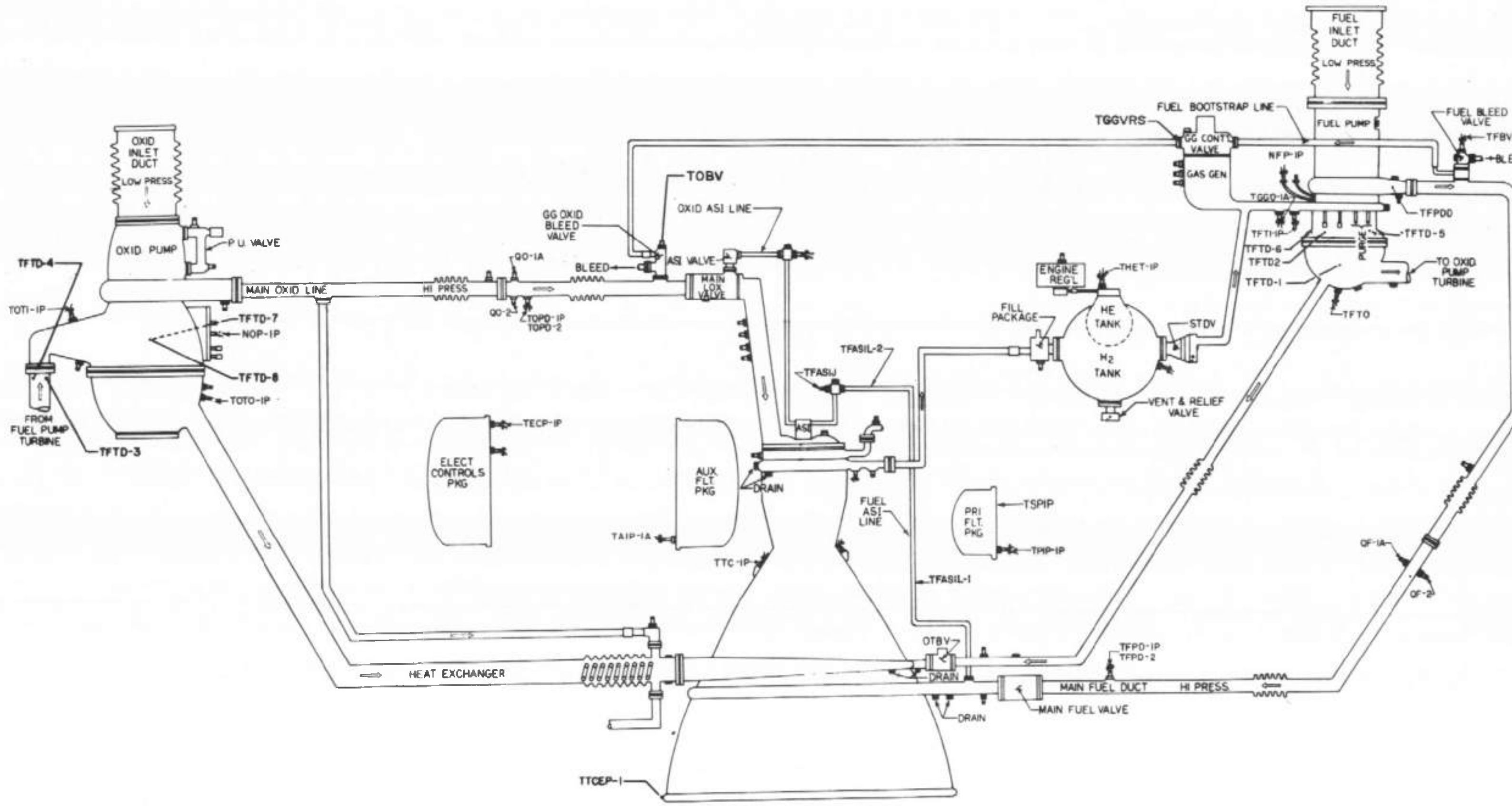
AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TSOVAL-1	Oxidizer Valve Closing Control Line		-200 to +100	x				
TSOVC-1	Oxidizer Valve Actuator Cap		-325 to +150	x			x	
TSTC	Start Tank Cooditiooing		-350 to +150	x				
TSTDVOC	Start Tank Discharge Valve Opening Cootrol Port		-350 to +100	x			x	
TTC-1P	Thrust Chamber Jacket (Control)	CS1	-425 to +500	x			x	
TTC-2	Thrust Chamber Jacket (Cootrol)	CS1A	-425 to +500	x			x	
TTCEP-1	Thrust Chamber Exit		-425 to +500	x				
TTPP	Turbopump Purge		-150 to +150	x			x	
	Vibrations		g					
UFPR	Fuel Pump Radial 90 deg		±200		x	x		
UOPR	Oxidizer Pump Radial 90 deg		±200		x			
UTCD-1	Thrust Chamber Dome		±500		x	x		
UTCD-2	Thrust Chamber Dome		±500		x	x		
UTCD-3(1)(2)	Thrust Chamber Dome		±500		x	x		
UTCD-4	Thrust Chamber Dome		±500		x	x		
U1VSC	No. 1 Vibration Safety Counts		On/Off			x		
U2VSC	No. 2 Vibration Safety Counts		On/Off			x		
	Voltage		volts					
VCB	Cootrol Bus		0 to 36	x		x		
VIB	Ignition Bus		0 to 36	x		x		
VIDA	Ignition Detect Amplifier		9 to 16	x		x		
VPUTEP	Propellant Utilization Valve Excitatioo		0 to 5	x				

(1) Used oo test 34 only
(2) Used oo all tests after test 34

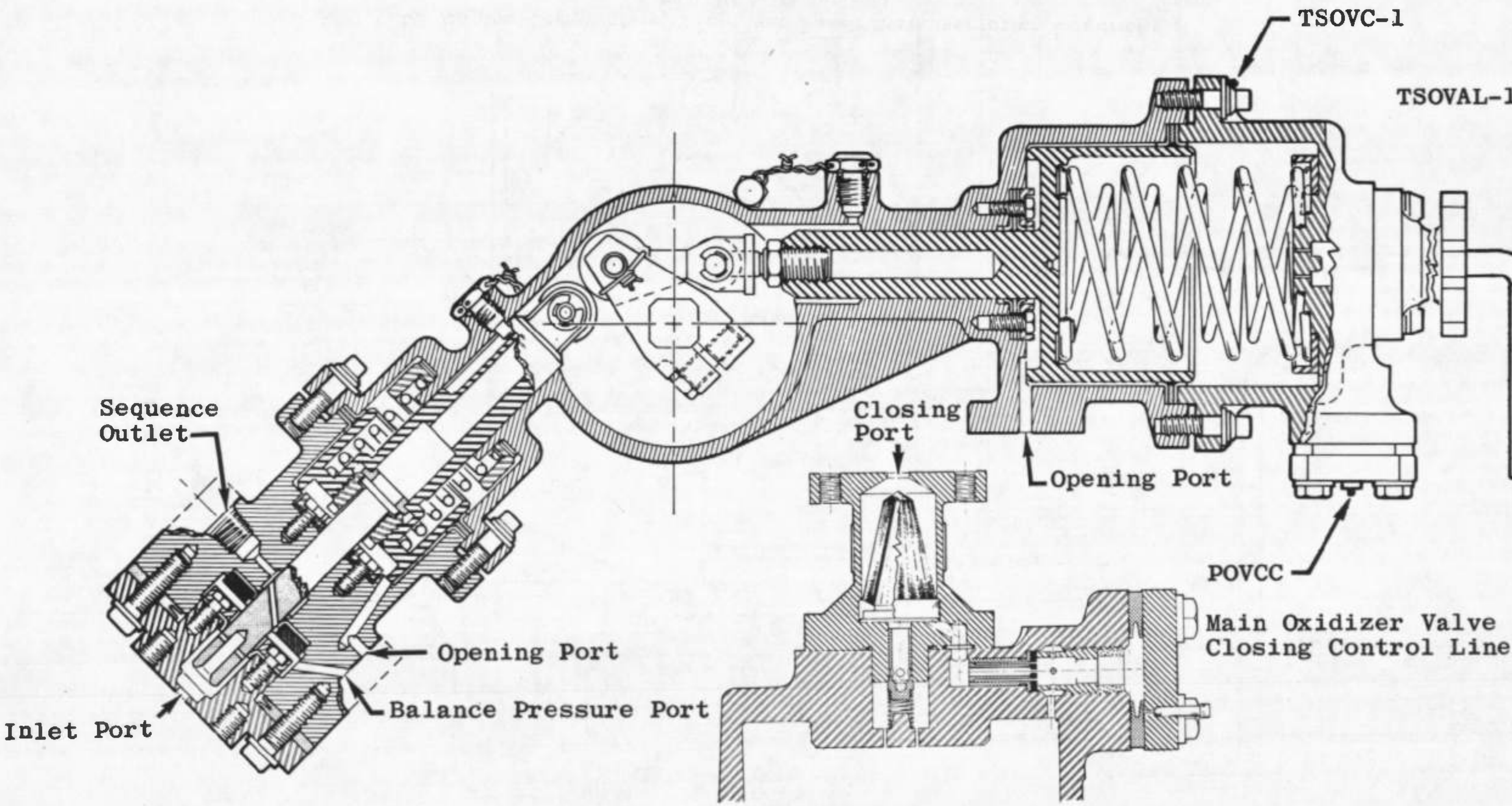


a. Engine Pressure Tap Locations

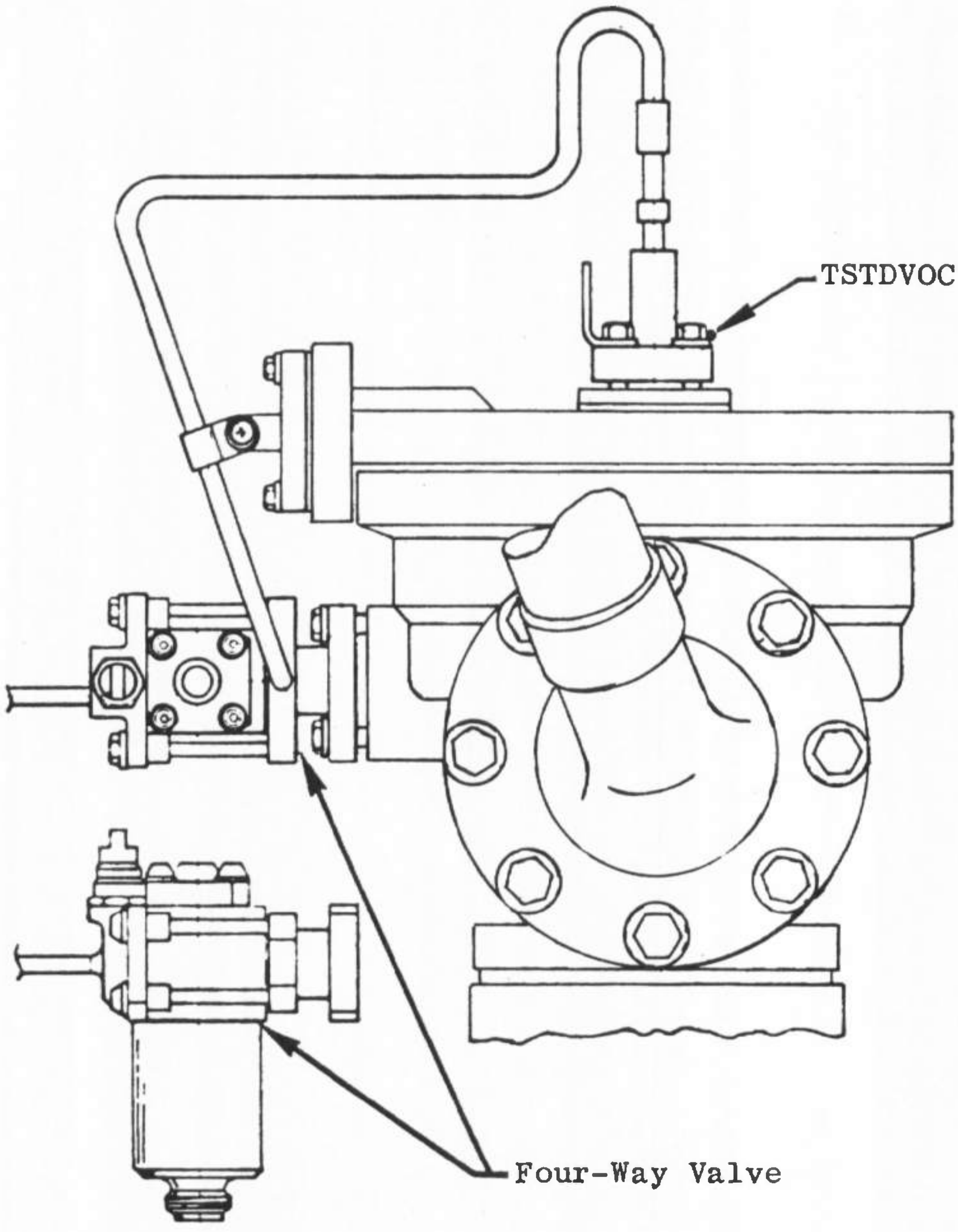
Fig. III-1 Instrumentation Locations



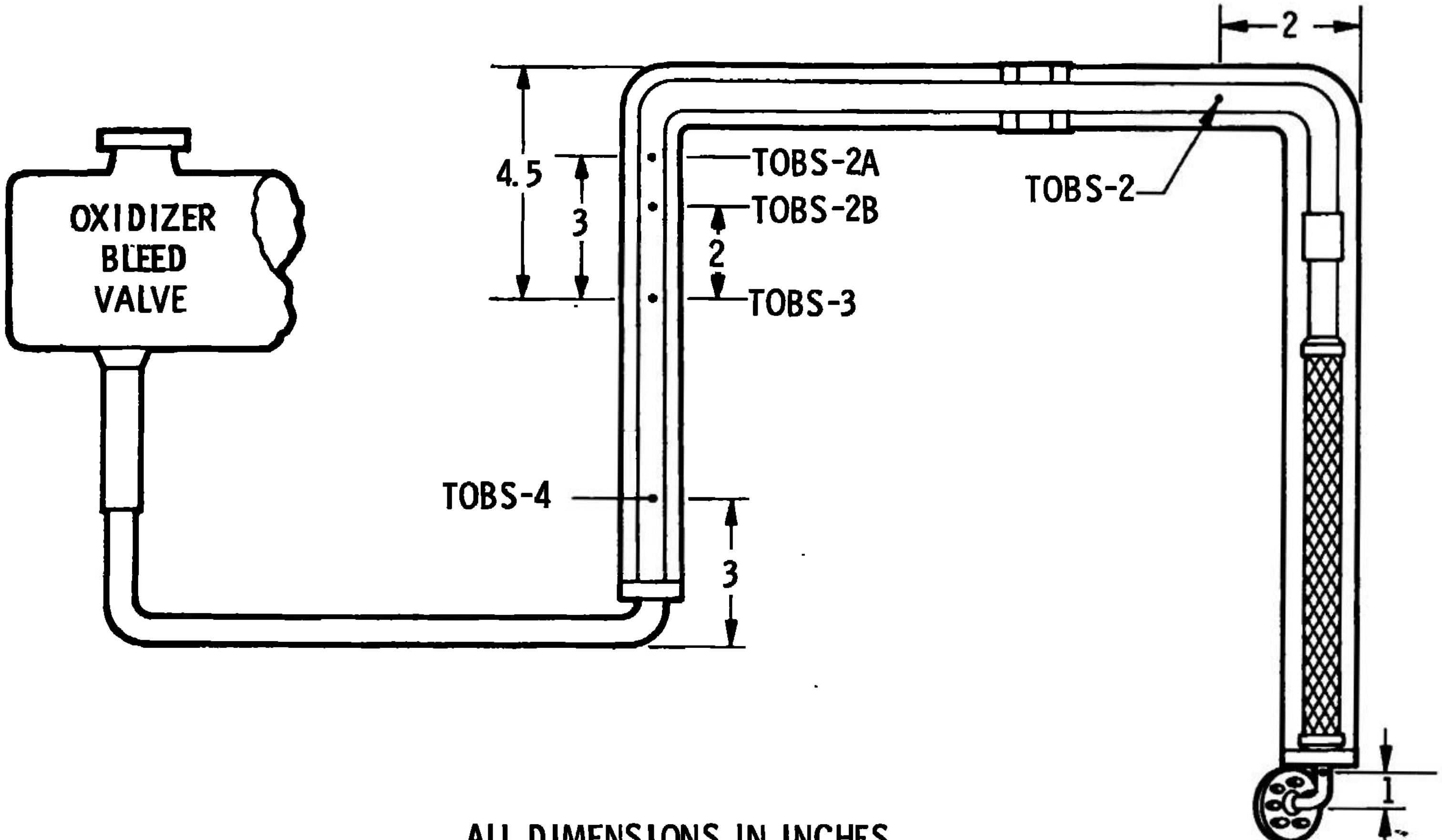
b. Engine Temperature, Flow, and Speed Instrumentation Locations
Fig. III-1 Continued



c. Main Oxidizer Valve
Fig. III-1 Continued



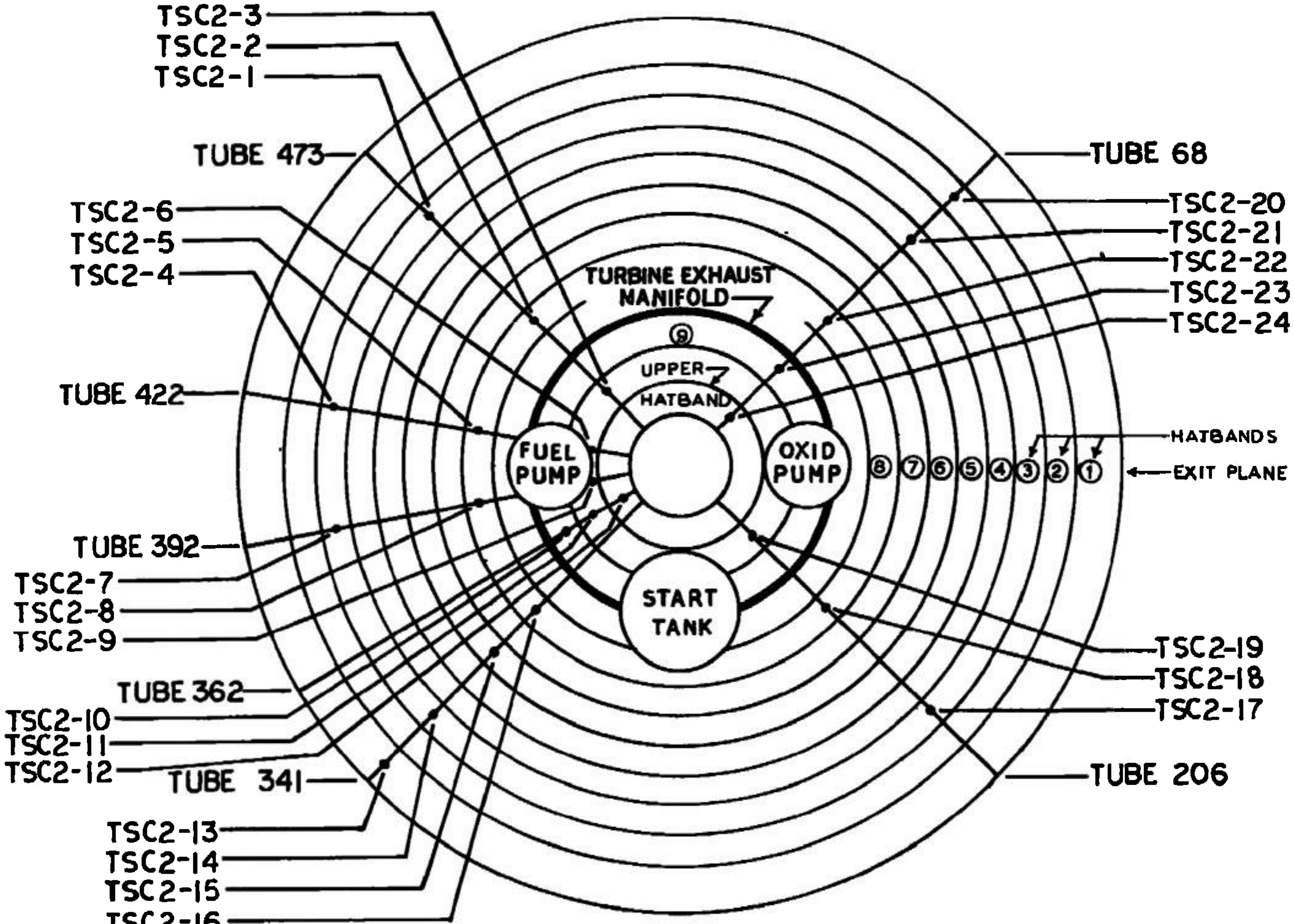
d. Start Tank Discharge Valve
Fig. III-1 Continued



ALL DIMENSIONS IN INCHES

e. Gas Generator Oxidizer Supply Line

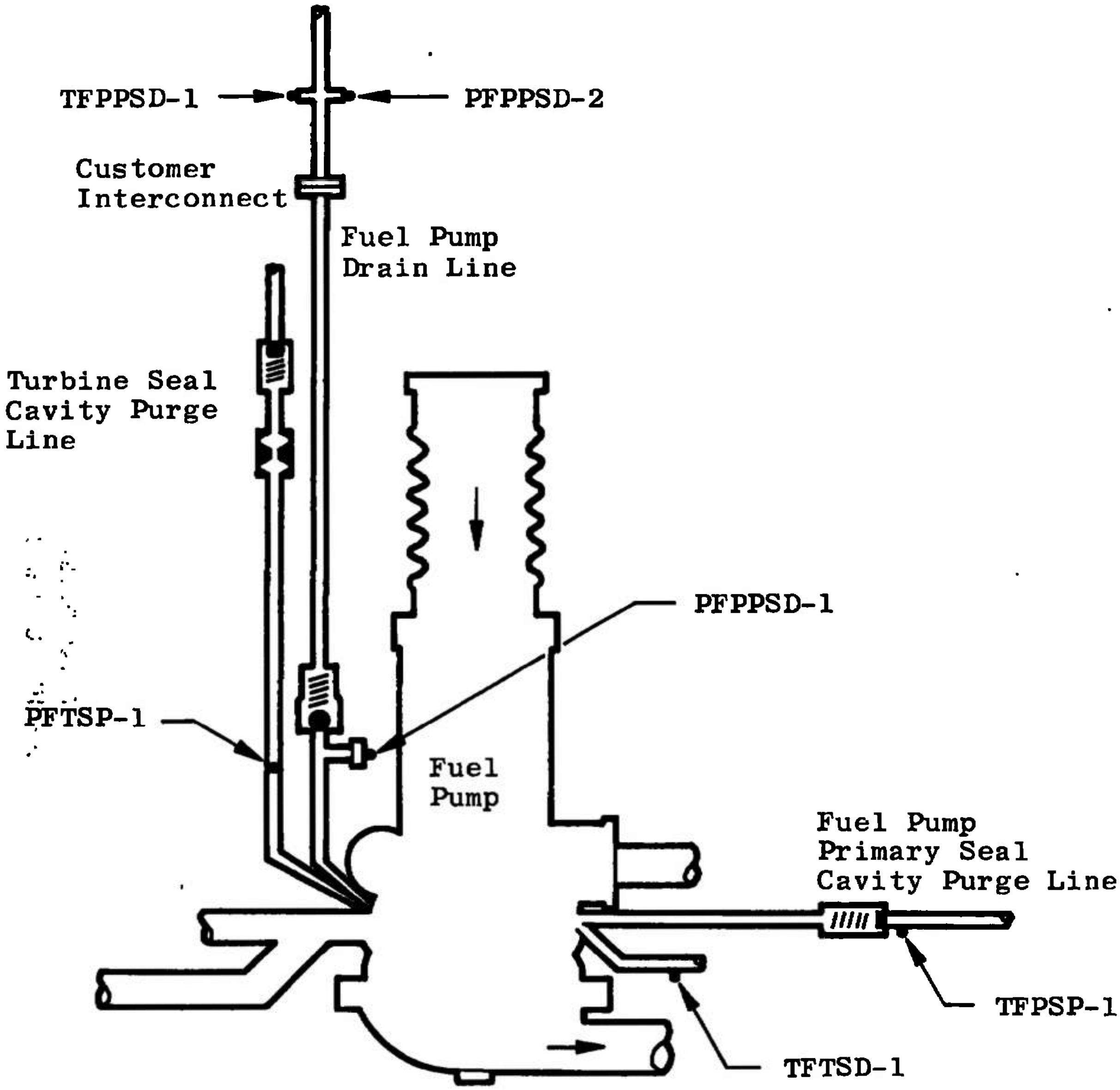
Fig. III-1 Continued



VIEW LOOKING AFT

f. Thrust Chamber

Fig. III-1 Continued



g. Fuel Turbopump Drain Line Pressure and Temperature Sensor Locations
Fig. III-1 Concluded

APPENDIX IV
METHODS OF CALCULATION (PERFORMANCE PROGRAM)

TABLE IV-1
PERFORMANCE PROGRAM DATA INPUTS

Item No.	Parameter
1	Thrust Chamber (Injector Face) Pressure, psia
2	Thrust Chamber Fuel and Oxidizer Injection Pressures, psia
3	Thrust Chamber Fuel Injection Temperature, °F
4	Fuel and Oxidizer Flowmeter Speeds, Hz
5	Fuel and Oxidizer Engine Inlet Pressures, psia
6	Fuel and Oxidizer Pump Discharge Pressures, psia
7	Fuel and Oxidizer Engine Inlet Temperatures, °F
8	Fuel and Oxidizer (Main Valves) Temperatures, °F
9	Propellant Utilization Valve Center Tap Voltage, volts
10	Propellant Utilization Valve Position, volts
11	Fuel and Oxidizer Pump Speeds, rpm
12	Gas Generator Chamber Pressure, psia
13	Gas Generator (Bootstrap Line at Bleed Valve) Temperature, °F
14	Fuel* and Oxidizer Turbine Inlet Pressure, psia
15	Oxidizer Turbine Discharge Pressure, psia
16	Fuel and Oxidizer Turbine Inlet Temperature, °F
17	Oxidizer Turbine Discharge Temperature, °F

*At AEDC, fuel turbine inlet pressure is calculated from gas generator chamber pressure.

NOMENCLATURE

A	Area, in.^{2}
B	Horsepower, hp
C*	Characteristic velocity, ft/sec
C_p	Specific heat at constant pressure, Btu/lb/°F
D	Diameter, in.
H	Head, ft
h	Enthalpy, Btu/lb_m
M	Molecular weight
N	Speed, rpm
P	Pressure, psia
Q	Flow rate, gpm
R	Resistance, sec^2/ft^3-in.^{2}
r	Mixture ratio
T	Temperature, °F
TC*	Theoretical characteristic velocity, ft/sec
W	Weight flow, lb/sec
Z	Pressure drop, psi
β	Ratio
γ	Ratio of specific heats
η	Efficiency
θ	Degrees
ρ	Density, lb/ft^3

SUBSCRIPTS

A	Ambient
AA	Ambient at thrust chamber exit
B	Bypass nozzle

BIR	Bypass nozzle inlet (Rankine)
BNI	Bypass nozzle inlet (total)
C	Thrust chamber
CF	Thrust chamber, fuel
CO	Thrust chamber, oxidizer
CV	Thrust chamber, vacuum
E	Engine
EF	Engine fuel
EM	Engine measured
EO	Engine oxidizer
EV	Engine, vacuum
e	Exit
em	Exit measured
F	Thrust
FIT	Fuel turbine inlet
FM	Fuel measured
FY	Thrust, vacuum
f	Fuel
G	Gas generator
GF	Gas generator fuel
GO	Gas generator oxidizer
H1	Hot gas duct No. 1
H1R	Hot gas duct No. 1 (Rankine)
H2R	Hot gas duct No. 2 (Rankine)
IF	Inlet fuel
IO	Inlet oxidizer
ITF	Isentropic turbine fuel
ITO	Isentropic turbine oxidizer
N	Nozzle
NB	Bypass nozzle (throat)

NV	Nozzle, vacuum
O	Oxidizer
OC	Oxidizer pump calculated
OF	Outlet fuel pump
OFIS	Outlet fuel pump isentropic
OM	Oxidizer measured
OO	Oxidizer outlet
PF	Pump fuel
PO	Pump oxidizer
PUVO	Propellant utilization valve oxidizer
RNC	Ratio bypass nozzle, critical
SC	Specific, thrust chamber
SCV	Specific thrust chamber, vacuum
SE	Specific, engine
SEV	Specific, engine vacuum
T	Total
T_o	Turbine oxidizer
TEF	Turbine exit fuel
TEFS	Turbine exit fuel (static)
TF	Fuel turbine
TIF	Turbine inlet fuel (total)
TIFM	Turbine inlet, fuel, measured
TIFS	Turbine inlet fuel isentropic
TIO	Turbine inlet oxidizer
t	Throat
V	Vacuum
v	Valve
XF	Fuel tank repressurant
XO	Oxidizer tank repressurant

PERFORMANCE PROGRAM EQUATIONS

MIXTURE RATIO

Engine

$$r_E = \frac{W_{EO}}{W_{EF}}$$

$$W_{EO} = W_{OM} - W_{XO}$$

$$W_{EF} = W_{FM} - W_{XF}$$

$$W_E = W_{EO} + W_{EF}$$

Thrust Chamber

$$r_C = \frac{W_{CO}}{W_{CF}}$$

$$W_{CO} = W_{OM} - W_{XO} - W_{GO}$$

$$W_{CF} = W_{FM} - W_{XF} - W_{GF}$$

$$W_{XO} = 0.9 \text{ lb/sec}$$

$$W_{XF} = 2.1 \text{ lb/sec}$$

$$W_{GO} = W_T - W_{GF}$$

$$W_{GF} = \frac{W_T}{1 + r_G}$$

$$W_T = \frac{P_{TIF}\ A_{TIF}\ K_7}{TC^*_{TIF}}$$

$$K_7 = 32.174$$

$$W_C = W_{CO} + W_{CF}$$

CHARACTERISTIC VELOCITY

Thrust Chamber

$$C^* = \frac{K_7\ P_c\ A_t}{W_C}$$

$$K_7 = 32.174$$

DEVELOPED PUMP HEAD

Flows are normalized by using the following inlet pressures, temperatures, and densities.

$$P_{IO} = 39 \text{ psia}$$
$$P_{IF} = 30 \text{ psia}$$
$$\rho_{IO} = 70.79 \text{ lb/ft}^3$$
$$\rho_{IF} = 4.40 \text{ lb/ft}^3$$
$$T_{IO} = -295.212\,^\circ\text{F}$$
$$T_{IF} = -422.547\,^\circ\text{F}$$

Oxidizer

$$H_O = K_4 \left(\frac{P_{OO}}{\rho_{OO}} - \frac{P_{IO}}{\rho_{IO}}\right)$$
$$K_4 = 144$$
$$\rho = \text{National Bureau of Standards Values f (P,T)}$$

Fuel

$$H_f = 778.16\,\Delta h_{OFIS}$$
$$\Delta h_{OFIS} = h_{OFIS} - h_{IF}$$
$$h_{OFIS} = f(P,T)$$
$$h_{IF} = f(P,T)$$

PUMP EFFICIENCIES

Fuel, Isentropic

$$\eta_f = \frac{h_{OFIS} - h_{IF}}{h_{OF} - h_{IF}}$$
$$h_{OF} = f(P_{OF}, T_{OF})$$

Oxidizer, Isentropic

$$\eta_O = \eta_{OC}\, Y_O$$
$$\eta_{OC} = K_{40} \left(\frac{Q_{PO}}{N_O}\right)^2 + K_{50} \left(\frac{Q_{PO}}{N_O}\right) + K_{60}$$
$$K_{40} = 5.0526$$
$$K_{50} = 3.8611$$
$$K_{60} = 0.0733$$
$$Y_O = 1.000$$

TURBINES

Oxidizer, Efficiency

$$\eta_{TO} = \frac{B_{TO}}{B_{ITO}}$$

$$B_{TO} = K_5 \frac{W_{PO} \; H_O}{\eta_O}$$

$$K_5 = 0.001818$$

$$W_{PO} = W_{OM} + W_{PUVO}$$

$$W_{PUVO} = \sqrt{\frac{Z_{PUVO} \; \rho_{OO}}{R_v}}$$

$$Z_{PUVO} = A + B \; (P_{OO})$$

$$A = -1597$$

$$B = 2.3828$$

IF $P_{OO} \geq 1010$ Set $P_{OO} = 1010$

$$\ln R_v = A_3 + B_3 (\theta_{PUVO}) + C (\theta_{PUVO})^3 + D_3 (e)^{\frac{\theta_{PUVO}}{7}} + E_3 (\theta_{PUVO}) (e)^{\frac{\theta_{PUVO}}{7}} + F_3 \left[(e)^{\frac{\theta_{PUVO}}{7}} \right]^2$$

$$A_3 = 5.5659 \times 10^{-1}$$

$$B_3 = 1.4997 \times 10^{-2}$$

$$C_3 = 7.9413 \times 10^{-6}$$

$$D_3 = 1.2343$$

$$E_3 = -7.2554 \times 10^{-2}$$

$$F_3 = 5.0691 \times 10^{-2}$$

$$\theta_{PUVO} = 16.5239$$

Fuel, Efficiency

$$\eta_{TF} = \frac{B_{TF}}{B_{ITF}}$$

$$B_{ITF} = K_{10} \; \Delta h_f \; W_T$$

$$\Delta h_f = h_{TIF} - h_{TEF}$$

$$B_{TF} = B_{PF} = K_5 \left(\frac{W_{PF} \; H_f}{\eta_f} \right)$$

$$W_{PF} = W_{FM}$$

$$K_{10} = 1.4148$$

$$K_5 = 0.001818$$

Oxidizer, Developed Horsepower

$$B_{TO} = B_{PO} + K_{56}$$

$$B_{PO} = K_5 \frac{W_{PO} H_O}{\eta_O}$$

$$K_{56} = -15$$

Fuel, Developed Horsepower

$$B_{TF} = B_{PF}$$

$$B_{PF} = K_5 \frac{W_{PF} H_f}{\eta_f}$$

$$W_{PF} = W_{FM}$$

Fuel, Weight Flow

$$W_{TF} = W_T$$

Oxidizer Weight Flow

$$W_{TO} = W_T - W_B$$

$$W_B = \left[\frac{2K_7 \gamma_{H2}}{\gamma_{H2-1}} (P_{RNC})^{\frac{2}{\gamma_{H2}}} \right]^{1/2} \left[1 - (P_{RNC})^{\frac{\gamma_{H2-1}}{\gamma_{H2}}} \right] \frac{A_{NB} P_{BNI}}{(R_{H2} T_{BIR})^{1/2}}$$

$$P_{RNC} = f(\beta_{NB}, \gamma_{H2})$$

$$\beta_{NB} = \frac{D_{NB}}{D_B}$$

$$\gamma_{H2}, M_{H2} = f(T_{H2R}, r_G)$$

$$A_{NB} = K_{13} D_{NB}$$

$$K_{13} = 0.7854$$

$$T_{BIR} = T_{TIO} - 460$$

$$P_{BNI} = P_{TEFS}$$

P_{TEFS} = Iteration of P_{TEF}

$$P_{TEF} = P_{TEFS} \left[1 + K_8 \left(\frac{W_T}{P_{TEFS}} \right)^2 \frac{T_{H2R}}{D^4_{TEF} M_{H2}} \left(\frac{\gamma_{H2-1}}{\gamma_{H2}} \right) \right]^{\frac{\gamma_{H2}}{\gamma_{H2-1}}}$$

$$K_8 = 38.8983$$

GAS GENERATOR

Mixture Ratio

$$r_G = D_1 (T_{H1})^3 + C_1 (T_{H1})^2 + B_1 (T_{H1}) + A_1$$

$$A_1 = 0.2575$$

$$B_1 = 5.586 \times 10^{-4}$$

$$C_1 = -5.332 \times 10^{-9}$$

$$D_1 = 1.1312 \times 10^{-11}$$

$$T_{H1} = T_{TIFM}$$

Flows

$$TC^*_{TIF} = D_2 (T_{H1})^3 + C_2 (T_{H1})^2 + B_2 (T_{H1}) + A_2$$

$$A_2 = 4.4226 \times 10^3$$

$$B_2 = 3.2267$$

$$C_2 = -1.3790 \times 10^{-3}$$

$$D_2 = 2.6212 \times 10^{-7}$$

$$P_{TIF} = P_{TIFS}\left[1 + K_8\left(\frac{W_T}{P_{TIFS}}\right)^2 \frac{T_{H1R}}{D^4_{TIF}\, M_{H1}} \; \frac{\gamma_{H1} - 1}{\gamma_{H1}}\right]^{\frac{\gamma_{H1}}{\gamma_{H1}-1}}$$

$$K_8 = 38.8983$$

Note: P_{TIF} is determined by iteration.

$$T_{HIR} = T_{TIF}$$

$$M_{H1}, \gamma_{H1}, C_p, r_{H1} = f\,(T_{HIR}, r_G)$$

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13. ABSTRACT

Twelve firings of the Rocketdyne J-2 rocket engine (S/N 2047) were conducted in Test Cell J-4 of the Large Rocket Facility on March 27 and April 2 and 10, 1968. These firings were accomplished during test periods J4-1801-34, J4-1801-35, and J4-1801-36 at pressure altitudes of approximately 100,000 ft at engine start to investigate S-IVB (1) first burn firings, (2) 6-hr orbital coast restart simulation firings, (3) 80-min orbital coast restart simulation firings, and (4) a partial transition firing to evaluate thrust chamber conditioning temperature effects on engine start transients. Engine operation was satisfactorily accomplished for all firings. One abort resulted when a leak developed in the diaphragm of the engine pneumatic regulator. The accumulated firing duration for the three test periods was 205 sec. The total firing duration of this engine at AEDC through test period J4-1801-36 is 1141 sec resulting from 91 engine firings.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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altitude testing						
first burn firings						
orbital coast restarts						
thrust chamber temperatures						
engine operation						